Over the past two decades, the 5-year survival rates of implant-supported prostheses have increased significantly compared with those before the year 2000, while the incidence of biologic complications is basically unchanged; on the other hand, reports of prosthetic complications are appearing with greater frequency in current publications.1,2 Changes in normal occlusion that take place from adolescence throughout life as a result of mesiodistal tooth size reduction related to interproximal attrition, slight lingual inclination of the incisor, and posterior tooth mesial migration may produce additional complications in the implant-restored dentition.3 The consequences of changes in natural dentition in adults restored with implants have been recently reported. Up to 50.5% of adult patients may experience implant infraposition—relative to adjacent teeth and crestal bone—of 0.58 mm on average after periods of 4 to 18.5 years. Within this same period range, implant infraposition higher than 1 mm has shown a pooled prevalence of 20.8%. Another reported complication is loss of proximal contacts, reported in 46.3% of cases after mean observations of 4 to 7 years.4 While these complications may be expected in adults, they have been reported to be more pronounced when implant-supported restorations are placed in adolescents, where skeletal growth is intense.5

The World Health Organization (WHO) defines adolescents as individuals between the ages of 10 and 19 years. It is during the first half of adolescence—ages 9 to 14 years for girls and 10 to 16 years for boys—when significant anatomical changes begin.6 Growth

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**Purpose:** To evaluate the clinical outcomes of unsplinted implant-supported single crowns placed in adolescents, ages 10 to 19 years, and followed up from 5 to 15 years. **Materials and Methods:** This retrospective case series evaluated the outcomes of implant-supported single crowns placed in adolescents between June 2002 and January 2015. The patients were treated with locking-taper connection implants under a two-stage rehabilitation technique. The variables assessed included patient identification, age and reason for implant placement, implant dimensions, follow-up time, status at follow-up, and event description. To analyze peri-implant changes, bone crest level relative to the adjacent tooth was measured from periapical radiographs taken after implantation and the latest follow-up. A paired t test was performed to determine initial and follow-up differences, and data are shown as mean and 95% confidence interval. Cumulative Kaplan-Meier survival rates for implants and prostheses were calculated. **Results:** Twenty-one adolescent patients with ages ranging from 14 to 19 years, mainly 16 to 18 years, received a total of 37 implant-supported single crowns more frequently placed in the anterior maxilla as a result of congenital aplasia and trauma. Mean changes in bone crests were 1.99 (± 0.4) mm at the day of crown insertion and 2.23 (± 0.4) mm at the latest follow-up (average: 10 years; P = .08). No implant was lost during the follow-up period, leading to 100% implant survival. A total of 34 surviving crowns and 3 crown failures at the time of the latest follow-up led to a cumulative survival rate of 70%. The most commonly observed event was loss of proximal contacts and infraocclusion, which were handled chairside by adding resin composite. **Conclusion:** Unsplinted implant-supported single crowns placed in adolescents showed high implant and prosthesis survival rates, with a mean bone crest level increase of approximately 0.23 mm relative to the adjacent teeth. *Int J Oral Maxillofac Implants* 2021;36:561–568. doi: 10.11607/jomi.8574

**Keywords:** adolescents, dental implants, survival rates

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of the jaws takes place in transverse, anteroposterior, and vertical planes with a differing chronology in the maxilla and mandible as well as within each individual jaw. Since physical appearance is of major importance during adolescence, unmet treatment needs result in psychosocial distress and social acceptance impairment. As a result, tooth loss due to trauma, disease, or aplasia in adolescents pressures clinicians, parents, and patients to seek restoration at earlier ages. Although several treatment options are available until growth has ceased, including orthodontic treatment, semi-permanent use of mini-implants, single-retainer resin-bonded prosthesis, or interim removable partial dentures, these have generally shown biologic complications—caries and periodontal issues; rather, the earliest possible placement of dental implants may be the preferred treatment. Aside from the social and aesthetic motivations, there are well-grounded dental reasons to consider implant therapy. In the absence of the stabilizing presence of a tooth or implant, the alveolar process will gradually resorb. By the time facial growth has slowed, surgical procedures may be required to augment the bone for implant placement. On the other hand, the effects of early implant placement have been well reported. Much like ankylosed deciduous teeth, the implant placed in early adolescence remains fixed in place, eg, in infraposition relative to the adjacent teeth and alveolar crest as growth takes place. Since age does not seem to correlate with individual variations in skeletal growth and dental maturation, the professional is challenged in determining the best time to place dental implants in adolescents. Systematic reviews have highlighted a lack of consensus regarding such timing, since the relation of facial growth and development to implant complications in the different areas of the arch has yet to be fully explored in long-term trials. Studies of patients receiving implants as early as 3 years of age for treatment of severe ectodermal dysplasia and at 10 years of age for dental trauma have reported that implants placed at these points of development are more likely to result in complications. The most common complication reported for implant-supported prostheses placed in adolescents is, not surprisingly, infraocclusion (more common in the maxilla), followed by the loss of prosthesis retention, and rotation of the prosthesis due to mandibular growth. More severe complications involving early implant placement may include pain/paresthesia, crestal bone loss adjacent to the implant and adjacent teeth, palatal positioning of the implant, marked infraocclusion of the implant, apicofacial fenestration of an implant placed in the maxillary anterior, and increased crown-to-implant ratio. Although the reported percentage of implant loss in adolescents may be up to 23.4%, which is much higher than that reported for adults and the elderly, implant placement has nonetheless been suggested as a viable treatment option in oligodontia cases, as long as areas of skeletal growth are respected, such as not crossing a suture line with a fixed implant-supported prosthesis, and that patients and their guardians are well informed.

The decision-making process for implant placement in adolescents—10 to 19 years of age according to WHO—seems very challenging. With this in mind, this retrospective case series sought to evaluate the clinical outcomes of implant-supported single crowns placed in this population, followed for up to 15 years, and to report the observed complications and their long-term management. The hypothesis was that adolescents restored with implant-supported crowns would present similar survival rates to those reported in the literature for grown adults, higher than 90% after 10 to 18 years of follow-up.

MATERIALS AND METHODS

This retrospective case series examined the outcomes of implant-supported single crowns placed in adolescents at the Implant Dentistry Centre (Boston, Massachusetts) between June 2002 and January 2015. Approval was obtained from the New England Institutional Review Board (protocol #120190479). Data were collected from files of patients who received implants and were restored with single crowns during adolescence (10 to 19 years of age according to WHO). Concerning reconstructive procedures, S.D. and L.M. were responsible for implant surgery and L.M. and M.H. for the restorative part. During the reconstructive phase, the patients (or their responsible family members) were instructed to fill out a standardized questionnaire with important aspects of systemic and oral history, including a detailed description of the systemic condition and medications. Patients who met the criteria for reconstructive procedures were also examined clinically and radiographically following a standardized protocol. Surgical, prosthodontic, or other complaints and all complications were immediately noted. Also, all patients were instructed to attend yearly follow-up examinations and/or in the occurrence of any complication. In all follow-up visits, the clinical and radiographic exams were performed following the standardized protocol. A software database (Dentrix, version 17.3.548, Henry Schein One) had been progressively created with patient information; thus, the current data were software-driven collected from the patient database, where the appropriate checks were set to restrict sample characteristics, avoiding bias.

The inclusion criteria were: (1) follow-up of restored implants (Bicon LLC) for least 5 years; (2) single-unit...
unsplinted Integrated Abutment Crowns (IACs; Bicon LLC), which are screwless one-unit crowns fabricated from an indirect composite directly layered onto abutments28; (3) crowns restored in only one implant system (Integra-CP, Bicon LLC) under a two-stage (restoration placed between 3 and 5 months after implant surgery) technique; (4) patients with satisfactory oral hygiene and without history of periodontal disease or tooth loss due to generalized caries; (5) completely healed sockets, at least 6 months postextraction; and (6) ASA I or II patients. The exclusion criteria were as follows: (1) patients who required previous bone or soft tissue grafting for implant placement; (2) contraindication for implant surgery due to systemic diseases; (3) general systemic contraindications (pregnancy, metabolic bone diseases, immunosuppression, etc); (4) previous/current bisphosphonate therapy; (5) prior radiation therapy (> 12 months) in the head and neck region; and (6) smokers and/or drug/alcohol addiction.

A database was created using Excel (Microsoft Office 365) with variables of interest to the study: patient gender, teeth involved, reason for implant placement, age at implant placement, implant dimensions, date of prosthesis insertion, follow-up time (serial time), status at serial time (event or censored), and event description.29 Descriptive statistics were computed for all studied variables. Periapical radiographs, taken by the extension cone paralleling system (Rinn, Dentsply) on the day of crown insertion were compared with those taken at the most recent follow-up visit. Considering the particular interest in maxillary/mandibular growth in adolescents, the primary outcome evaluated was bone level changes observed during the cohort. Implant dimensions collected from patient charts were used to calibrate the images and to compensate for possible distortion of the radiographs. Linear distances between the implant-abutment connection platform and the top of the mesial and distal alveolar bone crest of the adjacent tooth were measured (ImageJ, National Institutes of Health) from patient charts were used to calibrate the images and to compensate for possible distortion of the radiographs. Linear distances between the implant-abutment connection platform and the top of the mesial and distal alveolar bone crest of the adjacent tooth were measured (ImageJ, National Institutes of Health) for each implant.30 All measurements were performed by only one examiner (E.T.P.B.), and intraclass correlation coefficient (ICC) scores indicated strong reliability (0.98 with 1-week difference between measurements). The optimal sample size to achieve a power of 80% and a level of significance of 5% (two-sided) within an effect size of 0.8 was 15 (G*Power 3.1, HHU University). Data were analyzed using a mixed model with random intercepts for subjects. Data are presented as a function of mean and 95% confidence interval. Subsequently, cumulative Kaplan-Meier survival and success rates for implants and prostheses were calculated. Survival was defined as the implant-supported restoration complex remaining in situ at the latest follow-up visit with or without modifications. Success was determined according to the Albrektsson et al (1986) and Papapryidakos et al (2012) criteria.31,32 All analyses were accomplished using SPSS (SPSS ver. 26, IBM).

RESULTS

Patient Cohort

The final cohort was comprised of 21 adolescent patients fitting the inclusion criteria (13 female/62% and 8 male/38%) with ages ranging from 14 to 19 years at the time of implantation (average: 17.3 years; 17.2 years for females and 17.5 years for males) followed up for an average period of 10 years. Distribution of implants as a function of age showed that the majority were placed on adolescents 18 years of age (n = 18), followed by 16 years (n = 7), 17 years (n = 5), 19 years (n = 4), 15 years (n = 2), and 14 years (n = 1; Fig 1a). The patients received a total of 37 implant-supported single restorations more frequently placed in the anterior maxilla (n = 33; Fig 1b) due to congenital aplasia (n = 23), trauma (n = 13), and others (n = 1; Fig 1c). All implants placed in the posterior or region were due to congenital aplasia (n = 4; Fig 1b). While 20 implants were evaluated from 5 to 10 years of follow-up, 7 implants were analyzed after 10 years, and 10 implants between 10 and 15 years (Fig 2a). The majority of implants placed were short implants (> 6 to < 10 mm, n = 24). Seven placed implants were of standard length (≥ 10 mm to < 13 mm), and 4 were extrashort implants (5 mm; Fig 2b). The implant platform comprised standard-diameter implants (≥ 3.75 to < 5 mm; n = 23), followed by narrow (≥ 3.0 mm to < 3.75 mm, n = 7) and wide (> 5 mm, n = 5) diameter (Fig 2c).33

Bone Level Changes, Complications, and Survival

The mean baseline measurement of the mesial and distal bone crests of adjacent natural teeth relative to the implant platform was 1.99 (± 0.4) mm at the day of crown insertion and 2.23 (± 0.4) mm at the latest follow-up visit (0.23-mm bone increase, average follow-up 9 years; P = .01; Fig 3).

No implants were lost during the follow-up period, nor were there reports of inflammation of peri-implant tissues eventually leading to bone loss and/or loss of implants. Therefore, 100% implant success was observed according to the Albrektsson and Papapryidakos criteria.31,32

On the prosthetic level, the overall outcome showed a total of 34 surviving crowns and 3 crown failures at the time of the latest follow-up. Out of the three replaced crowns, two were in patients 14 and 15 years of age, resulting from anterior crown infraposition that adversely affected esthetics. The other replaced crown was due to fracture on a self-reported sleep bruxism patient. The
cumulative survival rate of the single crowns was 95% after the mean observation period of 10 years. The estimated cumulative survival rate at the 15-year follow-up was 70% (Fig 4).

At the time of the latest follow-up, of the 34 surviving crowns, a total of 20 demonstrated no need for intervention, and 14 presented a complication that was managed chairside. The most commonly observed event was loss of incisal/occlusal contacts, recorded for six crowns. These infrapositions were remedied by adding resin composite (Ceramage, Shofu, Japan) to the incisal or occlusal surface chairside. Loss of proximal

Fig 1  Implant distribution as a function of (a) age, (b) tooth, and (c) reason for implant placement in the adolescent patient population included in the cohort.

Fig 2  Implant distribution as a function of (a) follow-up time and implant dimensions, (b) length and (c) diameter, in the adolescent patient population included in the cohort.

Fig 3  Crestal bone-to-implant distance at the day of crown insertion and the latest follow-up. Time point comparison indicated absence of statistically significant difference ($P = .186$).
contacts, usually on the mesial surface of the crowns, was observed \( (n = 3) \) as well as abutment margin metal exposure \( (n = 3) \), both solved chairside by adding resin composite for continued function. Crown loosening occurred in two events and was associated with proximal contact loss and self-reported sleep bruxism. The Kaplan-Meier curve (Fig 5) of the mean 10-year follow-up period showed a cumulative success rate of 54%, with an estimated cumulative success rate for implant-supported restoration complexes at 27% after 15 years.

When outcomes were distributed as a function of age, the majority of censored patients or those presenting an event were observed when reconstructions were examined after 5 to 10 years (Table 2). This was also expected since most restorations in this cohort were examined after 5 to 10 years of implant placement (Fig 2a).

**DISCUSSION**

This retrospective case series study evaluated implant and prosthetic cumulative survival and success rates and described complications in 21 adolescents who received 37 implant-supported single-unit crowns followed up for an average period of 10 years (5 to 15 years). Overall, there were 3 crown failures and 34 survivals, of which 14 required chairside maintenance for continued function; thus, a 70% cumulative estimated survival rate after 15 years was determined. The postulated hypothesis that adolescents restored with implant-supported
crowns would present similar survival rates to those reported in the literature for grown adults, higher than 90% after 10 to 18 years of follow-up,^1,2,5–27 was rejected. Although the majority of implants were placed in patients in the 16 to 19 years of age range, where dynamic facial growth still takes place, none of the patients with successfully osseointegrated implants required surgical treatment to manage growth-related complications, which were entirely prosthetic in nature. Though these complications were minor and did not affect prosthetic survival, they resulted in a cumulative success rate of 27%. This suggests that clinicians and patients must be aware of the need for additional treatment time and costs when placing implants during adolescence. In the present cohort, loss of proximal contacts was frequently associated with the need to reinsert loose prostheses. It is of interest that intact proximal contacts provide an antirotational effect. When proximal contacts are lost, mainly due to skeletal growth in this sample population, the implant is exposed to off-axis loading, which affects load distribution to the prosthetic components, and the crown may loosen.44

While there is insufficient evidence to contraindicate the placement of dental implants in adolescents, caution must be taken in the decision-making process since most studies derive from case reports of patients restored at varying ages, restorative techniques, and outcome measurements.11 Systematic reviews on the topic generally agree that long-term trials with robust sample sizes are warranted^10,11; however, it must also be acknowledged that the most common reason for missing teeth in adolescents is congenitally missing lateral incisors, which has a reported prevalence of only 3.77%, with a higher frequency in female compared with male patients.35 With such a low frequency and considering the crown may loosen,34

The indication of semi-permanent treatments also presents drawbacks, such as irreversible loss of tooth structure even in single-retainer resin-bonded bridges, and increasing the risk of caries, periodontal complications, and alveolar resorption when removable appliances are used.8,9 Alternatives to reduce issues with implant treatment in adolescents have been proposed, including implant coronal placement to offset vertical growth.6 However, implant position recommendations may vary depending on the implant design, and in spite of that, they should primarily consider the broad variation in alveolar process development within different facial types and the consequent different patterns of facial growth.37 In the present cohort, implants were on average 1.99 (± 0.4) mm subcrestally at the time of crown insertion, and the present finding of a slight increase in that distance, 2.23 (± 0.4) mm, was expected since some residual growth likely took place and was reflected clinically in the infraposition of the restorations. From a restorative perspective, the implant-abutment connection design plays a role in marginal bone level changes where internal connections present lower marginal bone loss than external connections.38 Considering that screwed-in internal connections are, in essence, a male-to-female engagement where space between the implant well and abutment external surface must exist for proper fit, microorganism colonization at such interfaces has been reported.39,40

The locking-taper connection used in this study has been shown to hinder bacterial invasion in the implant well41; this is likely due to its interference fit mechanics comprised of its small taper angle and long contact length.42,43 Whether differences in implant-abutment connection designs impact crestal bone level remodeling in the restored implant adolescent population is yet to be confirmed.

Suggested techniques to manage implants in infraposition include replacement of implant-supported prostheses (performed in two of the present cases), distraction osteogenesis, and intrusion of adjacent teeth and extrusion of opposing teeth.11 Since the IAC restorations used in this study were all fabricated from an indirect resin composite material, chairside maintenance to address infraposition of incisal edge, occlusal surface, or loss of proximal contacts could be pragmatically accomplished by roughening, and layering of an adhesive bonding system and resin composites, as previously reported.44,45

Potential issues with growth spurts have been shown to be more significant at 12 years of age for girls and at 14 years of age for boys, with possible variations of as much as 6 years.37 It has been suggested that the most problematic ages are 9 to 15 years for girls and 11 to 17 years for boys.46 The present study cohort consisted mostly of patients in late adolescence (16 to 19 years of age), who, irrespective of gender, experienced a vertical crestal bone level change of approximately 0.23 mm, which is slightly lower than the approximately 0.58 mm previously reported in the literature.4 Thus, when a clinician is planning the use of oral implants in adolescents, tracking growth stages by hand/wrist radiographs and accounting for growth patterns that vary according to differing facial types (wide face and long face) becomes paramount. This sort of preparation is essential in understanding the stage of alveolar
process development and its impact on the clinical option for implant treatment, as well as anticipating the 3D effects of implant placement.\textsuperscript{6} Thilander et al (1994) also indicated that patient age, skeletal maturation stage, and estimates of total residual height growth all had a significant effect on the amount of observed infraposition of the restorations. Older/more skeletally mature patients showed less variation and a higher predictability of clinical outcomes.\textsuperscript{5}

Indications for implant placement in adolescents are either controversial or even contraindicated.\textsuperscript{5,10,11} However, the failure to establish a direct relationship between facial type and age on the risk for infraposition suggests that this undesirable consequence may not be solely age-dependent. Similar risks of infraposition have been reported in higher age groups (0.1 to 1.7 mm and 0.1 to 1.8 mm of vertical step in late adolescents and mature adults, respectively, after approximately 4.2 years).\textsuperscript{16} These findings are not surprising since infraposition of ankylosed permanent teeth has been reported in patients aged 20 to 30 years.\textsuperscript{47} Also, continued growth throughout adult years has been reported in patients from 23 to 65 years of age.\textsuperscript{48} A recent systematic review, based on studies of eight case reports and series, postulated that due to a lack of prospective long-term trials, there was insufficient evidence to either indicate, or contraindicate, implant therapy in adolescents. High survival rates have been reported, with clinically managed infraposition being the only reported complication (11 of 16 cases).\textsuperscript{11} However, such encouraging assumptions should be interpreted with caution due to the type of included studies as well as the use of different parameters to indicate success criteria. Therefore, outcomes of implants placed in adolescents should be further investigated.

Although 2D radiographic measurement tools are classical methods,\textsuperscript{16,30} they are particularly limited by dimensional alterations and impractical volume quantification.\textsuperscript{49} To overcome these limitations, the use of 3D and volumetric analysis has recently gained popularity due to accurate structural reconstruction and volumetric quantification to study changes in hard tissue contour.\textsuperscript{50,51} Thus, future studies with a robust sample size (with a more equal gender distribution and age range), skeletal growth follow-up using not only the classical method (hand/wrist radiograph) but also microcomputed tomography (micro-CT) reconstructions, and intraoral scans for a precise characterization of alterations in the alveolar bone are warranted in an effort to develop guidelines that more accurately identify the best treatment time for the placement of implants in adolescents.

CONCLUSIONS

Single-unit unsplinted crowns placed in adolescents showed high implant and prosthesis survival rates, with a mean bone crest level increase of approximately 0.23 mm relative to the adjacent teeth during the follow-up period. Additional time and costs for chairside maintenance on the prosthetic level should be expected by patients and clinicians.

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