

# Long-Term Outcomes of Dental Implants with a Titanium Plasma-Sprayed Surface: A 20-Year Prospective Case Series Study in Partially Edentulous Patients

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## ABSTRACT

*Background:* Long-term studies of  $\geq 10$  years are important milestones to get a better understanding of potential factors causing implant failures or complications.

*Purpose:* The present study investigated the long-term outcomes of titanium dental implants with a rough, microporous surface (titanium plasma sprayed [TPS]) and the associated biologic and technical complications in partially edentulous patients with fixed dental prostheses over a 20-year follow-up period.

*Materials and Methods:* Sixty-seven patients, who received 95 implants in the 1980s, were examined with well-established clinical and radiographic parameters. Based on these findings, each implant was classified as either successful, surviving, or failed.

*Results:* Ten implants in nine patients were lost during the observation period, resulting in an implant survival rate of 89.5%. Radiographically, 92% of the implants exhibited crestal bone loss below 1 mm between the 1- and 20-year follow-up examinations. Only 8% yielded peri-implant bone loss of  $>1$  mm and none exhibited severe bone loss of more than 1.8 mm. During the observation period, 19 implants (20%) experienced a biologic complication with suppuration. Of these 19 implants, 13 implants (13.7%) had been treated and were successfully maintained over the 20-year follow-up period. Therefore, the 20-year implant success rate was 75.8 or 89.5% depending on the different success criteria. Technical complications were observed in 32%.

*Conclusion:* The present study is the first to report satisfactory success rates after 20 years of function of dental implants with a TPS surface in partially edentulous patients.

**KEY WORDS:** biological complications, crestal bone loss, dental implant, implant survival rate, implant success rate, peri-implant bone loss, prospective follow-up study, technical complications, titanium plasma sprayed

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## INTRODUCTION

In relation to the increasing human life expectancy, long-term studies have become important milestones in the clinical assessment of medical and dental treatment concepts.<sup>1</sup> They not only provide important knowledge about how extended exposure to microflora affects hard and soft tissues around implants but also elucidate potential weaknesses of dental implants leading

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to biologic and technical complications. Longer-term follow-up studies of more than 20 years assessing dental implants with a titanium plasma-sprayed (TPS) surface have not been available until today.

A major paradigm shift was initiated in reconstructive dental medicine with the introduction of osseointegrated titanium implants.<sup>2,3</sup> Early research focused on titanium implants with two different surfaces: a machined, minimally rough titanium surface and a TPS surface that is rather rough and microporous.<sup>4,5</sup> The first clinical long-term studies achieved favorable results with minimally rough surfaces in fully edentulous patients, exhibiting survival rates between 78 and 86% after 15 years of function.<sup>6,7</sup> The development of rough TPS surfaces revealed excellent bone-to-implant contact and high removal torque values.<sup>8,9</sup> Rough TPS implants yielded 10-year survival and success rates between 82.9 and 96.6%.<sup>10-14</sup>

Despite relatively high success rates, implant failures do occur over time, either due to peri-implant infections, progressive bone loss, loss of osseointegration, or implant fracture.<sup>15,16</sup> To further optimize the long-term success rates of dental implants, a better understanding of the frequency and nature of implant failures, together with their potential contributing factors, is essential. In recent publications, a rather high prevalence of peri-implantitis and progressive bone loss has been reported at least for minimally rough and rough implant surfaces,<sup>17-21</sup> whereas other recent studies have reported a much lower frequency of peri-implantitis with modern, moderately rough surfaces.<sup>22,23</sup> The influence of implant surface and design characteristics on the incidence of peri-implant bone loss is limited and has been discussed recently.<sup>24</sup> There is ongoing debate not only over how these results should be interpreted but also how these findings would influence longer-term results of dental implants.<sup>25</sup>

The lack of longer-term data for rough dental implants in partially edentulous patients encouraged us to examine the treatment outcomes of dental implants with a TPS surface after 20 years of function. Despite the fact that this implant surface, as well as this design, was removed from the market more than 10 years ago, this study contributes to an understanding of the potential factors leading to implant failure or potential complications. The goal of the study was not only to examine the course of the peri-implant bone levels and soft tissue conditions over a 20-year period but also to assess the survival and success rates associated with the biologic and technical complications.

## MATERIALS AND METHODS

### Patient Cohort and Clinical Procedures

The protocol of the 20-year examination was approved by the standing ethical committee (Kantonale Ethikkommission) of the state of Bern (Protocol number 078/09). The study was conducted according to the principles stated in the Declaration of Helsinki (version 2008; <http://www.wma.net/en/30publications/10policies/b3/17c.pdf>).

The present investigation is a continuation of a prospective clinical trial that examined treatment outcomes after insertion of dental implants with a TPS surface after 1, 3, 5, and 8 years.<sup>10,26-28</sup> The original patient cohort consisted of 98 partially edentulous patients receiving 145 implants. These patients were treated surgically in the Department of Oral Surgery and Stomatology at the University of Bern between 1986 and 1989. Patients with severe health problems or presenting with local bone deficiency requiring bone augmentation were excluded. All inserted implants were either hollow screw (HS) or hollow cylinder (HC) implants with a rough, microporous TPS surface (Bonefit System, Institute Straumann AG, Basel, Switzerland).<sup>29</sup> The implants had been placed according to a standard implant placement protocol.<sup>29,30</sup> After a healing period of 3 to 6 months, the implants were restored with either single-unit crowns (SCs) or short-span fixed dental prostheses (FDPs). The annual follow-up examinations included a periapical radiograph and a clinical assessment, as described previously.<sup>26</sup>

At the 20-year examination, information related to medical conditions, medications, smoking history, self-reported biological and technical complications, and enrollment in a maintenance care program was collected by means of a questionnaire and from the patients' charts. The investigation was initiated by obtaining intra-oral photographs and was followed by clinical and radiographic examinations.

### Assessment of the Peri-Implant Mucosa

For the present 20-year follow-up examination, the same clinical parameters described in the initial 1-year report were applied:<sup>26</sup> peri-implant suppuration, modified plaque index (mPLI),<sup>31</sup> modified sulcus bleeding index (mSBI),<sup>31</sup> probing depth (PD, in millimeter), distance between the implant shoulder and the mucosal margin (DIM, in millimeter), clinical attachment level

(CAL, in millimeter), width of the keratinized mucosa (KM), and mobility evaluated using the Periotest (Siemens AG, Bensheim, Germany; Periotest value [PTV]).<sup>32</sup> The clinical parameters were assessed at four sites (mesial, distal, buccal, and oral), and the median and the mean values ( $\pm$ standard error) of the four sites were calculated.

### Assessment of the Peri-Implant Bone Levels

The linear distance between the implant shoulder and the first visible bone-implant contact (DIB, in millimeter) was radiographically assessed. Periapical radiographs were taken by an experienced dental nurse using the long-cone technique to assess the DIB on the mesial and distal aspects.<sup>26,33,34</sup> The DIB was measured twice by two examiners reaching consensus (R.B. and U.B.). In the radiographs obtained at 1, 3, 5, 8, and 20 years for each implant, one DIB value was calculated as the average of the mesial and distal values in order to evaluate the long-term crestal bone level changes. A frequency analysis was performed to compare the 1-year DIB values with the 20-year values. The results were grouped according to bone gain (positive values) and bone loss (negative values) in steps of 0.5 mm.

### Assessment of Survival and Success Rates and Complications

Based on clinical and radiographic findings, the implants were classified as either *successful*, *surviving*, or *failed* using the success criteria of Buser and colleagues<sup>26</sup> (Table 1). Episodes of biologic complications were retrieved from the patients' charts and consisted of peri-implant mucositis and peri-implant infections with suppuration. Mechanical complications were defined as failures of prefabricated components, whereas technical

complications consisted in failures of the laboratory-fabricated suprastructures.<sup>35</sup>

### Statistical Analysis

All data were expressed as median, mean ( $\pm$ standard error), minimum, and maximum values. Statistical significance for the clinical and radiographic data over the follow-up period was determined using the nonparametric Brunner-Langer model for longitudinal data in factorial experiments.<sup>36</sup> *p* values of analysis of variance-type statistics were calculated for time and/or group effects including their interaction. A *p* value of less than .05 (\*) was considered statistically significant. All statistical analyses were calculated using an open source R software package (R 2.14.1, <http://www.r-project.org> R Development Core Team, Auckland, New Zealand).

## RESULTS

### Patient Cohort

Of the original 98 patients with 145 implants, 11 patients (18 implants) had passed away during the 20-year period. Of the remaining 87 patients, 20 patients (32 implants) were not able to attend the examination because they had moved away or were of advanced age and/or in poor medical condition. The dropout rate amounted to 20% for the 20-year study period, excluding the deceased patients. Consequently, 67 patients were available for the 20-year examination, consisting of 31 males and 36 females who had originally received a total of 95 implants. At the time of implant reevaluation, the age of the patients ranged between 39 and 95 years (mean age  $66.3 \pm 13$  years). Most patients (61 patients, 91%) had remained in a regular maintenance care program over the 20-year period, with check-ups at least once a year.

**TABLE 1** Survival and Success Classifications for Each Implant

Clinical Status	Classifications	<i>n</i>	%
Removed, lost, mobile, or fractured implant	Implant failure	10	10.5
Implant with a history of an acute infection with suppuration and progressive bone loss	Surviving implant	13	13.7
Implant with an acute infection with suppuration and progressive bone loss	Surviving implant	0	0
Implant fulfilling the success criteria	Successful implant	72	75.8
Total		95	100
20-year implant success rate by Buser and colleagues <sup>26</sup>			75.8
20-year implant success rate by Albrektsson and colleagues <sup>60</sup>			89.5
20-year implant survival rate			89.5

**TABLE 2** Distribution of Implants by Type, Length, and Jaw

Implant Type/Length	Maxilla	Mandible	n	%
<b>Hollow screw (HS)</b>				
8 mm	3	7	10	9
10 mm	7	31	38	42
12 mm	5	18	23	24
<b>Subtotal HS</b>	<b>15</b>	<b>56</b>	<b>71</b>	<b>75</b>
<b>Hollow cylinder (HC)</b>				
8 mm	3	1	4	4
10 mm	12	0	12	13
12 mm	7	1	8	8
<b>Subtotal HC</b>	<b>22</b>	<b>2</b>	<b>24</b>	<b>25</b>
<b>Total</b>	<b>37</b>	<b>58</b>	<b>95</b>	<b>100</b>

### Implant Types, Implant Locations, and Implant-Supported Reconstructions

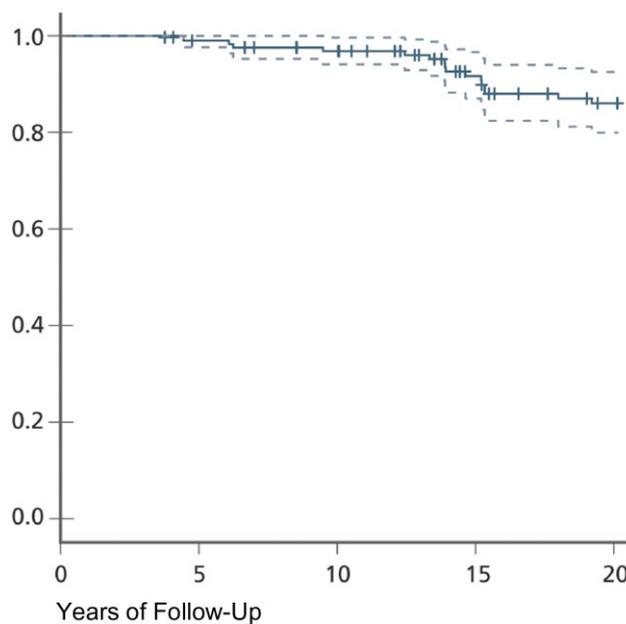
At the time of examination, all implants had been in function for at least 20 years (mean observation period 21 years; range 20–23 years). Of the 95 initially inserted implants, 71 were HS (75%) and 24 were HC (25%) implants. The most frequently used implant length was 10 mm (55%, Table 2). The sites of implant placement were either in the anterior maxilla (37; 39%) or in the posterior mandible (58; 61%; Tables 2 and 3).

The 95 implants supported 75 fixed ceramometal reconstructions consisting of SCs ( $n = 33$ ; 33 implants), splinted SCs ( $n = 2$ ; four implants), implant-supported FDPs ( $n = 13$ ; 26 implants), implant-tooth-supported FDPs ( $n = 24$ ; 27 implants), or FDPs with one cantilever extension ( $n = 3$ ; five implants). Sixty-six reconstructions were cemented, whereas nine were screw retained.

### Failure Rates and Incidence of Biologic and Technical Complications

Out of the 95 implants, a total of 10 implants in nine patients were lost during the observation period result-

Survival Probability



**Figure 1** Survival probability by Kaplan-Meier analysis.

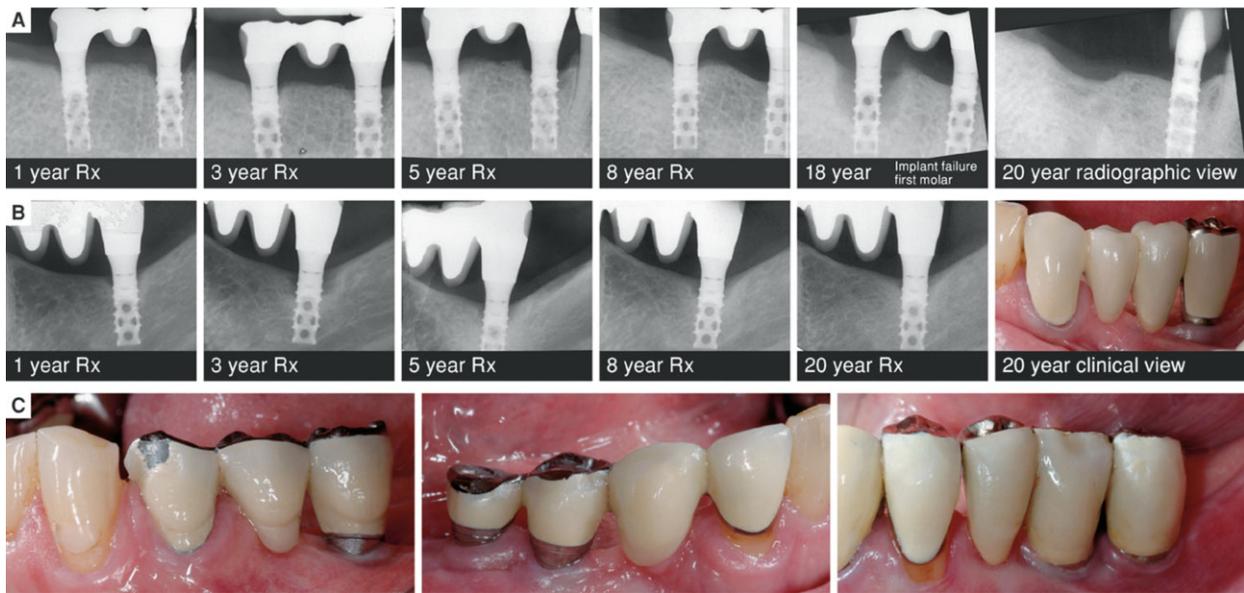
ing in an implant failure rate of 10.5% (Table 1). Most implant failures were localized in the anterior maxilla (seven implants), whereas three implants were lost in mandibular molar sites. The causes of the 10 implant failures were implant fractures in three HS implants after 15 to 16 years, one implant removal at the patient’s request after 14 years of function, and biologic complications in six implants due to ongoing peri-implant infections with progressive bone loss between 4 and 19 years (Figures 1 and 2A).

During the 20-year observation period, biologic complications were recorded for 24 implants. Of these, five exhibited peri-implant mucositis. Nineteen implants were associated with peri-implant infections with suppuration and bone loss. In the case of six implants, the anti-infectious therapy was not successful and the implants had to be removed. The remaining 13 implants were treated and healthy peri-implant tissues

**TABLE 3** Distribution of Implants by Location

Number	Number of Implants per Location															
	0	0	2	1	2	2	3	6	4	3	5	6	2	1	0	0
Implant location*	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
<b>Number</b>	<b>1</b>	<b>7</b>	<b>12</b>	<b>6</b>	<b>3</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>2</b>	<b>6</b>	<b>14</b>	<b>7</b>	<b>0</b>

\*Locations according to the World Health Organization classification.



**Figure 2** Case series of implant complications. (A) Implant failure: case series of an implant failure due to biological complications at 18 years. (B) Biological complication: case series of biological complications 3 years following implant placement. A combination of local disinfectant measures and systemic antibiotic treatment was used in this specific case. Thereafter, the implant was successful. (C) Technical complication: the most frequent technical complication was ceramic chipping or slight crown fracture.

were successfully maintained, showing no signs of acute infection at the 20-year examination (Figure 2B).

During the examination, nine of the total 75 prostheses had to be removed due to implant failure. These failures affected three SCs, three implant-supported FDPs, and three implant-tooth-supported FDPs. Three restorations had to be renewed, one due to a severe crown fracture and two for unknown reasons, resulting in a total prosthesis failure rate of 16%. Mechanical complications related to prefabricated components were observed in one patient with a fractured abutment in an FDP with one cantilever and twice with screw loosening in two patients (3%). Technical complications related to ceramic chipping of the laboratory-fabricated

prostheses were found in nearly every third prosthesis (28%, Figure 2C).

### Peri-Implant Mucosa at the 20-Year Examination

The 85 examined implants showed a healthy peri-implant mucosa overall and no signs of pain or peri-implant infection with suppuration. This is documented by low plaque and bleeding indices (Tables 4 and 5). Throughout the 20-year observation period, the PD, CAL, and DIM values remained stable and without statistically significant differences (*p* values: .08, .22, and .11, respectively). However, the width of KM on the facial/buccal aspect of the implants exhibited a

TABLE 4 Clinical Peri-Implant Parameter of the 85 Implants												
	1-Year Observation						20-Year Observation					
	mPLI	mSBI	PD	DIM	CAL	KM	mPLI	mSBI	PD	DIM	CAL	KM
Minimum	0	0	1.25	2.00	0.25	0.00	0	0	1.50	5.25	1.00	0.00
Maximum	2.75	2	5.25	-2.50	5.25	8.00	3	2	7.25	-4.75	10.75	8.00
Median	0	0	3.00	0.00	3.00	3.00	0	0	3.00	-0.50	3.00	2.00
Mean	0.25	0.29	3.05	-0.15	2.90	3.51	0.44	0.11	3.14	-0.26	2.87	2.06
SD	0.58	0.62	0.83	0.91	0.98	1.66	0.64	0.41	0.95	1.59	1.49	1.58

mPLI, modified plaque index; mSBI, modified sulcus bleeding index; PD, probing depth in millimeter; DIM, distance between the implant shoulder and the mucosal margin in millimeter; CAL, clinical attachment level in millimeter; KM, keratinized mucosa; SD, standard deviation.

**TABLE 5** Evaluation of Self-Performed Oral Hygiene by mPLI and mSBI

Frequency	Score 0	Score 1	Score 2	Score 3	Frequency	Score 0	Score 1	Score 2	Score 3
mPLI 1 year	83%	10%	6%	1%	mSBI 1 year	80%	11%	9%	0%
mPLI 20 years	64%	28%	7%	1%	mSBI 20 years	92%	5%	3%	0%
<i>p</i> Value	<.0001*				<i>p</i> Value	<.0017*			

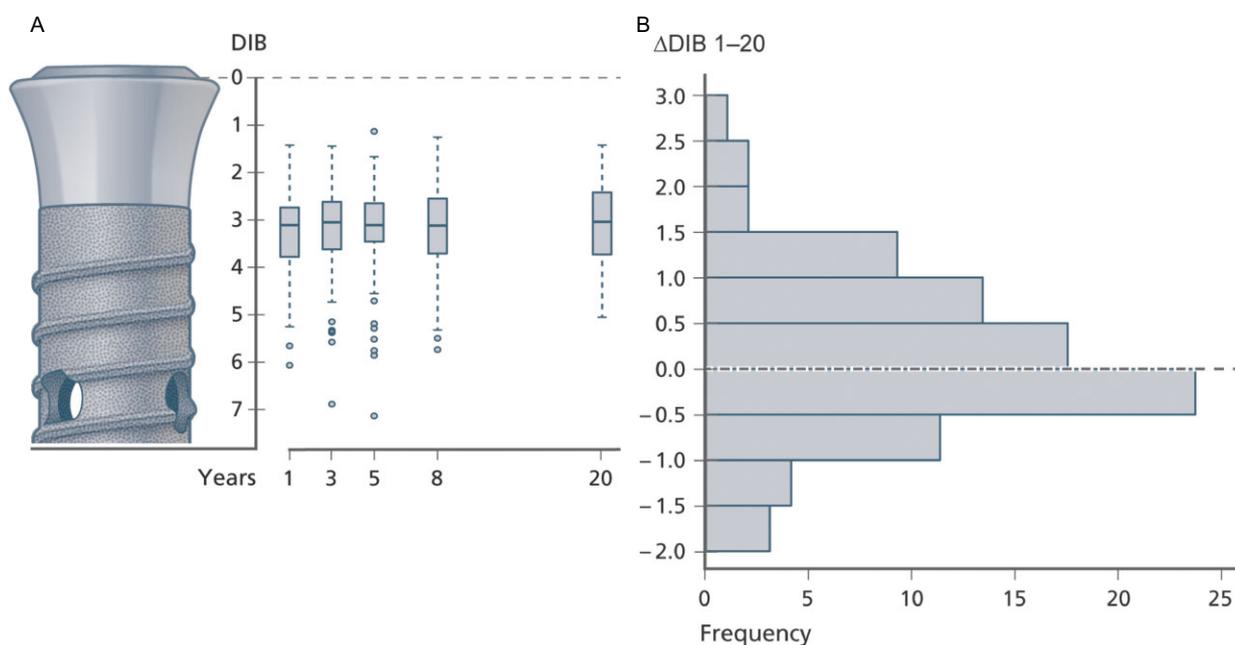
Frequency comparison of all measurements between the first and the 20th year. A *p* value of less than 0.05(\*) was considered statistically significant. mPLI, modified plaque index; mSBI, modified sulcus bleeding index.

significant decrease from the 1- to the 20-year follow-up (*p* value <.0001).

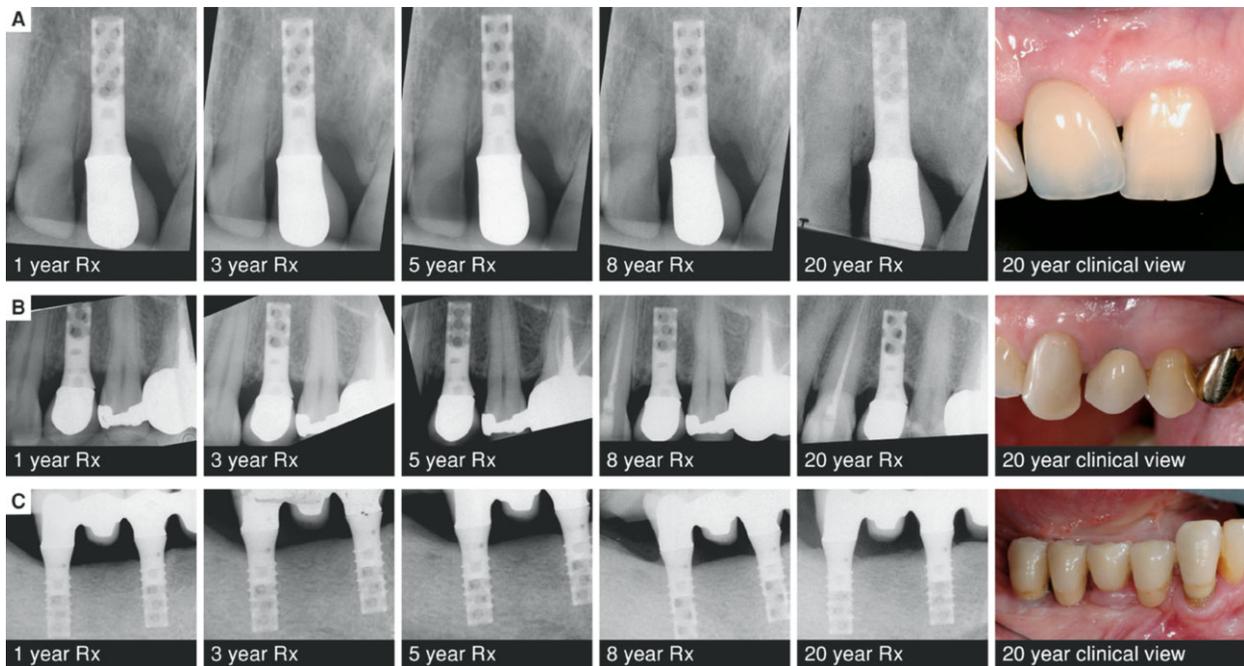
### Peri-Implant Bone Levels at the 20-Year Examination

The DIB values of the 85 implants exhibited stable peri-implant bone levels over the 20-year follow-up period (Figure 3A). The changes in median DIB values over time were not statistically significant from the 1-year (3.11 mm), to the 3-year (3.05 mm), to the 5-year (3.11 mm), to the 8-year (3.12 mm), and to the 20-year (3.04 mm) examination (*p* = .12) (Figure 3A). In order to assess the peri-implant bone stability after the initial bone modeling, the DIB value at the first-year examination was subtracted from the DIB value at the 20-year examination ( $\Delta$ DIB<sub>1-20 years</sub>) and a frequency

analysis was performed. These bone level changes between 1 and 20 years ( $\Delta$ DIB<sub>1-20 years</sub>) ranged from a maximum bone loss of -1.8 mm to a maximum bone gain of 3 mm (Figure 3B). Overall, 92% of the implants exhibited either crestal bone gain or minimal bone loss below 1 mm over the 20-year follow-up period (Figure 3B). Of those, 64 implants (75%) showed minimal crestal bone alterations between -1.0 and +1.0 mm (Figures 3B and 4B), whereas 14 implants (17%) gained bone level of between +1.1 and +3.0 mm (Figures 3B and 4C). The remaining seven implants (8%) revealed moderate bone loss of <-1.0 to -1.8 mm (Figures 3B and 4A). No implant lost more than 1.8 mm during the 20-year study period. Although heavy cigarette smokers revealed more severe peri-implant bone loss over the 20-year observation period, the correlation



**Figure 3** Peri-implant bone level over an observation period of 20 years. (A) Box plot of the distance between the implant shoulder and the first visible bone-implant contact (DIB) values at 1-, 3-, 5-, 8-, and 20-year examination revealed no statistically significant differences (*p* = .1). (B) Frequency analysis of the  $\Delta$ DIB<sub>1-20 years</sub> values exhibiting bone loss (negative values) and bone gain (positive values).



**Figure 4** Case series of peri-implant bone level changes. (A) Moderate marginal bone loss: clinical case series showing the implant with the maximum bone loss of  $-1.8$  mm. (B) Minimal marginal bone loss: clinical case series showing an implant with bone level changes between  $0.5$  and  $-0.5$  mm. (C) Moderate marginal bone gain: clinical case series showing implants with marginal bone level gain.

between marginal bone levels and smoking habits showed no significant time and group effects over time.

### Implant Survival and Success Rates

Summarizing the above-mentioned clinical and radiological findings, the 10 implant failures resulted in a 20-year implant survival rate of 89.5% (Table 1). The 13 implants with a history of an acute peri-implant infection with suppuration were classified as surviving implants. Consequently, the remaining 72 implants, which fulfilled the success criteria during the entire 20-year study period, were classified as successful implants, resulting in a 20-year implant success rate of 75.8% (Table 1).

### DISCUSSION

The present study is the first to report true success rates of dental implants with a TPS surface in partially edentulous patients over a 20-year follow-up period. It is based on a continuation of a prospective clinical trial.<sup>10,26–28</sup> This pioneer group of patients yielded healthy peri-implant soft tissue conditions and stable peri-implant bone crest levels at the 20-year examination. Even though these implants revealed a rather rough and microporous surface, the analysis demon-

strated that 92% of the implants showed peri-implant bone loss of less than 1 mm over the 20-year observation period (Figure 3). Despite the favorable soft and hard tissue conditions, 10 implants in nine patients were lost during the observation period, resulting in a survival rate of 89.5% (Figure 1). A history of peri-implant suppuration with crestal bone loss was reported in 13 implants, which were classified as surviving implants, leading to a success rate of 75.8% according to Buser and colleagues.<sup>26</sup> It has to be pointed out that these surviving implants were successfully treated and maintained over the 20-year examination period (Figure 2B).

Peri-implant bone loss is the key parameter affecting implant success.<sup>37</sup> Many studies have investigated potential factors that are able to modulate peri-implant bone levels, mainly focusing on implant design or surface characteristics. The stable peri-implant bone levels over a 20-year period in the present study are remarkable as the HC and HS implant designs had certain disadvantages. First, the hollow body design not only facilitated implant fractures but also the invasion of potential pathogens into the transversal openings may favor advanced peri-implant bone loss.<sup>38,39</sup> Second, the TPS implant surface is microporous and clearly rougher

than modern, moderately rough surfaces mainly used today in implant dentistry.<sup>24</sup> Nevertheless, it appears that these disadvantages related to implant design and surface characteristics did not provoke severe bone loss in the majority of patients.

The evidence in the literature for the influence of implant surface characteristics on the incidence of peri-implant bone loss is limited. The rough TPS implant surface has been shown to result in increased peri-implant bone loss<sup>40,41</sup> or a higher frequency of peri-implantitis<sup>17</sup> than smoother implant surfaces, whereas moderately rough or minimally rough surfaces did not report significant differences.<sup>42–45</sup> The findings of minimal peri-implant bone level changes in the present cohort are supported by Lekholm and colleagues,<sup>46</sup> who examined titanium implants with a minimally rough surface in partially edentulous patients. Mean crestal bone loss of 1 mm around implants and 0.7 mm around teeth was observed over a 20-year period, which is similar to the present study. It was confirmed that few sites experienced severe bone loss (8.5% implant sites, 13.6% tooth sites), which also has been demonstrated in other 20-year follow-up studies in edentulous patients examining minimally rough titanium surfaces.<sup>47–49</sup>

Despite acceptable long-term survival and success rates, dental implants can experience biologic and technical complications. Biologic complication is a collective term describing either peri-implant mucositis as a reversible inflammatory process or peri-implantitis, which is characterized by peri-implant suppuration and progressive bone loss.<sup>20</sup> An important factor influencing biologic complications is oral hygiene.<sup>50–52</sup> In the present cohort study, the clinical parameters demonstrated good soft tissue health over the 20-year maintenance period. The high level of self-performed oral hygiene is supported by the fact that 91% of the patients remained in regular supportive care at least once a year during the 20-year follow-up period. Most of the clinical parameters showed no significant increase over the 20-year period (PD, DIM, and CAL; Tables 4 and 5). Even though bleeding indices significantly decreased (mSBI), plaque indices significantly increased up to the 20-year follow-up (mPLI), which may be related to the inability of some patients with advanced age to perform oral hygiene or to the significantly reduced width of KM, which has been discussed in the literature as a contributing factor for impaired plaque control.<sup>53–55</sup>

In the present study, no implant revealed signs of biologic complications at the 20-year evaluation. However, 19 implants had a history of a biologic complication with suppuration during the follow-up period. Of these, six implants failed and 13 implants had been treated and were successfully maintained over the 20-year follow-up period. Although effective treatment protocols for these complications were inconclusive two decades ago, these implants were successfully treated and maintained over the 20-year observation period. Implants with a history of biologic complications showed no significant differences in the peri-implant bone levels over time. These findings may imply that biologic complications had been identified at an early stage, long before severe progressive bone loss had become manifest. The study by Heitz-Mayfield and colleagues<sup>56</sup> supports the finding that the majority of patients exhibiting moderate to advanced peri-implantitis can be successfully treated after an observation period of 12 months. In contrast to biologic complications, technical complications were more frequently observed (32%). These technical complications comprised implant fractures, which were observed in three implants (3.2%) between 15 and 16 years of function. It had been assumed that the HS design, with its associated perforations, could predispose the implant to fracture.<sup>39,57</sup> The relatively low incidence of implant fractures over a 20-year observation period in the present study contradicts the above-mentioned hypothesis. This may imply that implant fractures are associated with multiple etiological factors.<sup>57</sup> The most frequent technical complication was found to be ceramic chipping (28%) of the ceramometal reconstructions. These findings are in agreement with other studies reporting a prevalence of technical complications between 31.1 and 38.7%.<sup>13,35,58</sup>

The lack of standardized and internationally recognized success criteria makes it difficult to compare studies. Ten-year success rates ranging between 63 and 95.9% for TPS implants have been reported using variable success criteria.<sup>11,12,59</sup> For longer-term studies, only survival rates are available. These vary between 91 and 99.2% and have been exclusively reported for edentulous patients with minimally rough implants.<sup>46–49</sup> The most commonly accepted criteria for the assessment of implant success were proposed by Albrektsson and colleagues<sup>60,61</sup> and Buser and colleagues.<sup>26</sup> According to the success criteria of Albrektsson and colleagues,<sup>60,61</sup>

peri-implant bone loss up to 0.2 mm annually after the first year is accepted, adding up to a total crestal bone loss of 3.8 mm after a 20-year observation period, which would classify the implant as a success. In the present study, none of the implants lost more than 1.8 mm over the 20-year period. Therefore, by the criteria of Albrektsson and colleagues,<sup>60,61</sup> all of the surviving implants would have been classified as successes, resulting in a survival and success rate of 89.5%. Using the criteria of Buser and colleagues,<sup>26</sup> implants experiencing an episode of peri-implant infection with suppuration were not classified as successful but as surviving implants. These strictly applied criteria resulted in a 20-year implant success rate of 75.8% (Table 1). These differences in the applied criteria become more evident in the evaluation of longer-term studies and point out the need for an internationally accepted consensus for the assessment of implant success rates in the future.

The present study has several limitations. First, although one surgeon had placed all implants, different investigators analyzed the treatment outcomes over the 20-year period. Second, the treatment of biologic complications was individualized and was not based on systematic treatment protocols; therefore, it is not possible to draw conclusions from the different treatment approaches.

In conclusion, the present study covering a unique pioneering group of partially edentulous patients demonstrated healthy soft tissue conditions and stable peri-implant bone crest levels after an observation period of 20 years. Even though the implant design and the TPS surface had been removed from the market, it appears that the drawbacks related to the implant design and surface characteristics did not provoke severe bone loss for the majority of implants. The survival rate of 89.5% and success rate of 75.6% appear acceptable when considering the treatment protocols and biomaterials available in the mid 1980s. It can be assumed that higher survival and success rates can be expected for modern, currently available implants due to the solid-screw design and improved microrough implant surfaces, which have shown survival rates clearly above 95% for 10-year observation periods.<sup>62–65</sup>

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