Implant-supported restorative therapy in a Swedish population

Complications and cost evaluations

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To my family
my mother, father
and Johan with love

Abstract

Replacing missing teeth through implant-supported restorative therapy is a common treatment procedure. While high survival rates have been reported, complications affecting the implant and/or the implant-supported reconstructions may occur. Such biological or technical complications require additional investment in treatment.

The aim of this thesis was (i) to evaluate the occurrence, consequences and possible clustering of implant-related complications, (ii) to assess interventions offered to patients diagnosed with advanced peri-implantitis and (iii) to evaluate costs associated with implant-supported restorative therapy and complications. All evaluations were performed in a Swedish population provided with implant-supported restorative therapy under everyday conditions, and based on analyses of patient records including radiographs.

Out of a cohort of 596 subjects, the proportion of patients experiencing technical and/or biological complications over a 9-year period was 42% **(Study III)**. One out of four patients experienced technical complications, chipping being the most common. The extent of restorative therapy was the strongest risk indicator for technical complications **(Study I)**. Patients diagnosed with peri-implantitis (n = 98) rarely received surgical therapy. Non-surgical interventions were insufficient in arresting disease progression **(Study II)**. Accumulated costs during the observation period were significantly higher in patients with full-jaw restorations compared to patients with partial-jaw and single-tooth restorations. Among all complications, implant loss generated the greatest additional costs **(Study IV)**.

Keywords

Dental implant, complication, peri-implantitis, risk factors, interventions, cost.

Sammanfattning på svenska

Att ersätta förlorade tänder med tandimplantat är ett vanligt förekommande behandlingsalternativ inom tandvården. Även om höga överlevnadstal har rapporterats för tandimplantat, kan olika typer av komplikationer inträffa som påverkar funktionen för den implantatstödda protetiska konstruktionen och/eller implantatet. Dessa tekniska och biologiska komplikationer medför behov av ytterligare vårdinsatser, vilka i sin tur leder till extra kostnader.

Målet med denna avhandling var att (i) analysera förekomsten och konsekvenser av implantat-relaterade komplikationer, (ii) utvärdera vilka typer av behandlingar som erbjudits patienter som diagnosticerats med avancerad peri-implantit, (iii) undersöka om vissa patientgrupper är mer drabbade än andra av olika typer av komplikationer och (iv), beräkna kostnaden för implantatstödd protetisk terapi och dess komplikationer. En svensk population som erhållit implantatbehandling på olika kliniker runtom i Sverige var grunden för alla analyser.

Andelen patienter som fick någon typ av komplikation under uppföljningsperioden på 9 år var 42% **(Studie III)**. Var fjärde patient drabbades av en teknisk komplikation, där fraktur av protestand var den vanligaste. Omfattningen av den implantatstödda protetiska konstruktionen var den starkaste riskfaktorn för att råka ut för en teknisk komplikation **(Studie I)**. Ett fåtal av de patienter som fått diagnosen peri-implantit erhöll kirurgisk behandling. Utförda icke-kirurgiska behandlingsåtgärder var otillräckliga för att förhindra sjukdomsprogression **(Studie II)**. De ackumulerade kostnaderna under uppföljningsperioden var signifikant högre för patienter med fullbrokonstruktioner jämfört med de som hade partiella eller singeltandsersättningar. Implantatförlust genererade den högsta adderade kostnaden jämfört med samtliga övriga typer av komplikationer **(Studie IV)**.

List of papers

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. Karlsson K, Derks J, Håkansson J, Wennström JL, Molin Thorén M, Petzold M, Berglundh T. (2018) Technical complications following implant-supported restorative therapy performed in Sweden. *Clinical Oral Implants Research. 29: 603–611.*

II. Karlsson K, Derks J, Håkansson J, Wennström JL, Petzold M, Berglundh T. (2019) Interventions for peri-implantitis and their effects on further bone loss: A retrospective analysis of a registry based cohort. *Journal of Clinical Periodontology. 46: 872-879.*

III. Karlsson K, Derks J, Wennström JL, Petzold M, Berglundh T. (2020) Occurrence and clustering of complications in implant dentistry. *Clinical Oral Implants Research. 31: 1002-1009.*

IV. Karlsson K, Derks J, Wennström JL, Petzold M, Berglundh T. (2021) Health economic aspects of implant-supported restorative therapy. *Manuscript.*

Content

Abbreviations

BoP	Bleeding on probing
CAL	Clinical attachment level
CSR	Cumulative survival rate
CI	Confidence interval
FDP	Fixed dental prosthesis
FPD	Fixed partial denture
OHRQoL	Oral Health-Related Quality-of-Life
OR	Odds ratio
PPD	Probing pocket depth
PROM	Patient-reported outcome measure
SD	Standard deviation
SE	Standard error
SkaPa	Swedish Quality Registry for Caries and Periodontal Disease
SSIA	Swedish Social Insurance Agency
SUP	Suppuration
TLV	Tandvårds- och läkemedelsförmånsverket (Dental and Pharmaceutical Benefits Agency in Sweden)

Introduction

Implant-supported restorative therapy

Implant-supported restorative therapy is today a common choice of treatment when rehabilitating patients who suffer from partial or complete edentulism. The number of implants placed worldwide is increasing. In Sweden, the therapy is widely used, illustrated by the >30 000 patients receiving dental implant therapy on an annual basis (Swedish Social Insurance Agency, SSIA, 2021). In addition, data from the last decade demonstrate a shift regarding the number of implants per patient, as there was a decline of patients with full-jaw restorations while the proportion of patients with single restorations increased (SKaPa annual report 2019). There are advantages related to implant-supported restorative therapy in comparison to tooth-supported fixed dental prostheses and removable dentures. Implant-supported single-tooth restorations allow for preservation of pristine neighbouring teeth and avoidance of complications which may occur in relation to tooth-supported restorative therapy, such as secondary caries, loss of vitality and endodontic problems (Pjetursson, Sailer, Makarov, Zwahlen, & Thoma, 2015; Sailer, Makarov, Thoma, Zwahlen, & Pjetursson, 2015). In relation to complete removable dentures, patients may be restored with implant-supported fixed restorations instead of, in some cases, ill-fitting removable prostheses, thus improving chewing function and quality-of-life (Heydecke, Locker, Awad, Lund, & Feine, 2003; Kutkut et al., 2018; Meijer, Raghoebar, & Van 't Hof, 2003). In fact, numerous studies have demonstrated the positive impact of implant therapy on oral health-related quality-of-life (OHRQoL). Patient satisfaction following treatment with implants was consistently shown to be high (Pjetursson, Karoussis, Burgin, Brägger, & Lang, 2005; Simonis, Dufour, & Tenenbaum, 2010).

Implant-supported restorations are, however, not free from problems. Patients who receive implant-supported restorative therapy may experience different sorts of complications such as porcelain chipping and fractures, loss of retention and peri-implantitis (Pjetursson, Thoma, Jung, Zwahlen, & Zembic, 2012; Sailer et al., 2018).

Relevant outcomes in studies on implant therapy

The survival rate of implants and implant-supported reconstructions, as well as implant loss, are outcomes frequently evaluated and presented in the literature. In fact, implant survival was described as the most frequently reported outcome in a review including 216 studies (Needleman, Chin, O'Brien, Petrie, & Donos, 2012). Implant loss is a final outcome and easily understood. The term survival describes an 'implant and fixed prosthesis present in the mouth independent of biological and/or technical complications' (Albrektsson, Jansson, & Lekholm, 1986). Using survival as an outcome excludes other types of events from the assessment, including functionality and patient comfort.

Success is another term commonly used in evaluations of implant therapy. The expression entails aspects on function, osseointegration, absence of pain and pathological processes and patient satisfaction. However, there is no consensus and the criteria considered for success in implant treatment vary (Albrektsson et al., 1986; Buser et al., 1997; Buser, Weber, & Lang, 1990; Karoussis et al., 2003; Smith & Zarb, 1989).

Due to the limitations of survival as an outcome parameter in the evaluation of implant therapy, an alternative approach may be considered. Thus, a complication-free survival rate would take any biological or technical complication, affecting implants and/or the prosthetic reconstruction, into account. Pjetursson et al. (2012), in a systematic review, reported a complication-free survival rate of 66.4% on the patient level after an observation period of at least 5 years. The survival rate of implant-supported reconstructions for the same period was 95.4%. In another review the calculated complication-free survival rate for metal-ceramic implant-supported reconstructions amounted to 84.9% while the survival rate was 98.7% on reconstruction level (Sailer et al., 2018).

Implant survival rate used as an outcome in the evaluation of implant therapy has several limitations since it disregards several critical factors such as function, aesthetics and peri-implant status. An additional aspect to consider when reporting on outcomes in implant therapy is the unit of analysis. Clustering of implants may influence results and, hence, statistical analyses

should consider multilevel modelling (Albandar & Goldstein, 1992). In the review by Needleman et al. (2012), 213 out of the 216 studies reported data on implants. Only three of the studies accounted for clustering, i.e. the presence of multiple implants in the same individual. In order to increase the clinical relevance of research on implant therapy, consensus reports from the 8th European Workshop on Periodontology stated that outcomes should be expressed at patient rather than at implant level (Sanz & Chapple, 2012; Tonetti & Palmer, 2012).

Table 1. Systematic reviews reporting on the outcome "complication-free" following implant therapy

First author, year	Number of included studies and time of follow-up	Type of material of the implant-supported reconstruction	Definition of "complication free"	Main findings
Pjetursson et al. (2012)	32 studies Mean follow-up of ≥5 years	Approximately 1/3 of FDPs were gold-acrylic and 2/3 of FDPs were metal-ceramic	An FDP being free of all complications over the entire observation period	66.4% of patients complication-free after 5 years (based on 5 of the 32 studies). Chipping: 13.5% Screw loosening: 5.3% Loss of retention (cemented): 4.7% Biological complications: 8.5%
Sailer et al. (2018)	19 studies Mean follow-up of ≥3 years	Metal-ceramic FDPs and zirconia-ceramic FDPs	An implant-supported FDP being free of all complications over the entire observation period	*Metal ceramic FDPs:* 84.9% free of complication (estimated 5-year success rate, based on 3 of the 19 studies). Chipping: 11.6% Screw loosening: 4.1% Biological complications: 3.1% (based on one study)

Table 2. Studies reporting on the outcome "complication-free" following implant therapy

First author, year	Study design, setting and time of follow-up	Sample size and type of reconstruction	Definition of "complication free"	Main findings
Adler et al. (2020)	Retrospective Specialist clinic, Stockholm, Sweden Mean 11 years (range 9-15 years)	376 patients Mix of single-crown, partial- and full-jaw re-constructions 1095 implants	Patient without biological or technical complication	Patients free of biological or technical complication at 10 years: 35%
Dierens et al. (2016)	Retrospective Specialist clinic, Malmö, Sweden Mean 18.5 years (range 16-22 years)	50 patients Single-crown reconstructions 62 implants	Patient free of any complication	Patients free of biological or technical complication at 16 years: 34%
Papaspyridakos et al. (2019)	Retrospective University, Boston, USA Mean 5.1 years (range 1-12 years)	19 patients 38 full-arch FDPs 249 implants	Prosthesis free of technical or biological complication (evaluated separately)	Prostheses free of biological complication: 10.5% Prostheses free of technical complication: 18.4%

Technical complications associated with implant-supported restorative therapy

"Technical complications" is a commonly used term in implant dentistry and refers to an impairment of the dental implant, the connecting parts or the implant-supported reconstruction. Such events may range from minor chipping fractures of veneering material to fractures of the implant resulting in implant loss. Examples are illustrated in Figure 1.

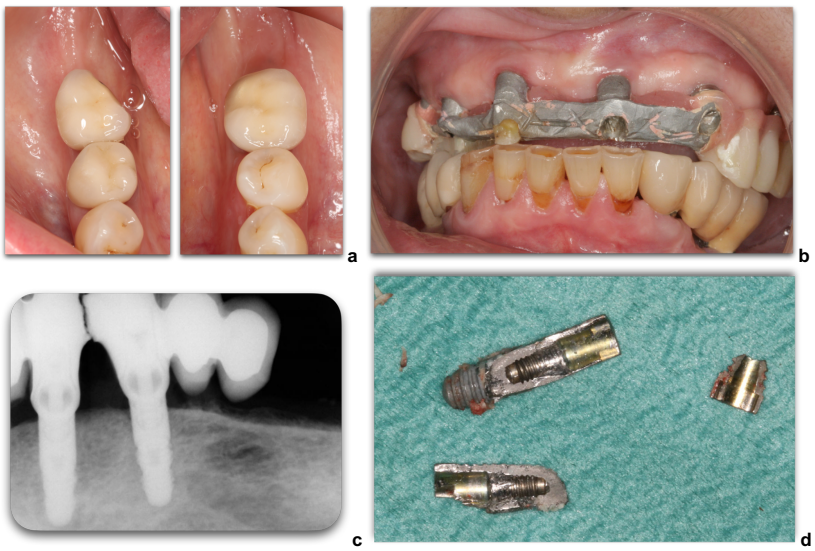


Figure 1 a) Chipping of porcelain on single crowns **b**) Fracture of acrylic part of implant-supported FDP **c**) Fracture of metal framework **d**) Implant fracture

Studies assessing technical complications

Different types and varying degrees of occurrence of technical complications in implant dentistry have been described (e.g. Brägger, Karoussis, et al. (2005), Brägger et al. (2011), Gotfredsen and Karlsson (2001), Kreissl, Gerds, Muche, Heydecke, and Strub (2007), Örtorp and Jemt (2009), Wennerberg and Jemt (1999), Wittneben et al. (2014)). In two recent Swedish studies (Adler et al.,

2020; Chrcanovic, Kisch, & Larsson, 2020b), technical complications were assessed over mean observation periods of 11 and 9 years, respectively. The proportion of patients experiencing at least one technical complication reported by Adler et al. (2020) was 32%. In the study by Chrcanovic et al. (2020a) technical complications occurred in 33.2% of reconstructions. Brägger et al. (2005) reported corresponding figures of 16.9% for patients and 13.7% for reconstructions.

Out of the various technical complications described in the literature, loosening of the occlusal screw, and chipping of the veneering material were the most frequent types. In the study by Adler et al. (2020) chipping occurred in 6.9% of patients and screw loosening in 7.8%. Wittneben et al. (2014) presented corresponding figures of 20.3% and 2.6%, respectively. In a 15-year follow-up study presented by Örtorp & Jemt (2009) 46.2% of patients experienced chipping and 3.1% screw loosening.

Data from the studies reported above indicate that types of technical complications vary. Thus, the technical complications considered in this thesis were (i) chipping of the veneering material of the prosthesis, (ii) fracture of the implant, framework or abutment screw, (iii) loss of retention (screw loosening or decementation) and (iv) misfit of the prosthetic reconstruction.

Risk factors for technical complications

Implant-supported reconstructions with multiple dental units, as opposed to single crowns, have been demonstrated to be at higher risk for chipping (Wittneben et al., 2014). Reconstructions with cantilevers have also proven to be at higher risk for complications as described by Kreissl et al (2007). Implant-supported cantilever fixed dental prostheses (FDPs) had the lowest event-free survival rate (67%; 95%CI: 50-87) after a mean follow-up period of 5 years compared to single crowns (78%; 95%CI: 53-100) and FDPs with no cantilevers (100%). Brägger et al. (2011) presented similar figures and demonstrated that 60% of implant-supported FDPs with cantilevers were free from any complication after 5 years compared to 89% of those without cantilevers.

Cantilevers were also identified as a risk factor for screw loosening by Chrcanovic et al. (2020b). The authors observed a significantly higher risk for screw loosening in one- and two-cantilever FDPs. The two cantilever-reconstructions presented with a hazard ratio of 3.7 compared to FDPs without cantilevers. FDPs with two pontics (HR 4.3), bruxism (HR 2.8) and type of abutment connection (internal connection HR 3.4 relative to external connection) were identified as risk factors for chipping in the same study.

Other parameters such as bruxism, implant location and irradiation have been demonstrated as risk factors for implant failure (Chrcanovic, Kisch, Albrektsson, & Wennerberg, 2018). Bruxism was also presented to be a risk factor for technical complications (Chrcanovic et al., 2020b; Chrcanovic, Kisch, & Larsson, 2020c).

Table 3. Studies on technical complications following implant-supported restorative therapy

First author, year	Study design, setting and time of follow-up	Sample size	Type of reconstruction	Main findings
Adler et al. (2020)	Retrospective Specialist clinic, Stockholm, Sweden 11 years	376 patients 1095 implants	Mix of single-crown, partial- and full-jaw reconstructions	Total: 32% Screw loosening: 7.8% Chipping: 6.9% (patient level)
Brägger et al. (2005)	Prospective University of Bern, Switzerland 10 years	48 patients (69 single-tooth reconstructions) 29 patients (69 implants, 33 reconstructions)	Mix of implant-supported single-crown reconstructions, implant-supported fixed dental prostheses (FDPs) and implant-tooth supported FDPs	Total: 16.9% (patient level) Total: 13.7% (reconstruction level, implant-supported)
Chrcanovic et al. (2020b)	Retrospective Specialist clinic, Malmö, Sweden 9 years	642 patients 876 reconstructions 2241 implants	2-6-unit FDPs, 254 with cantilever	Total: 33.2% Fractured acrylic teeth: 16.2% Fractured ceramic: 8.3% Loss of retention: 14.9% (reconstruction level)
Kreissl et al. (2007)	Prospective University hospital, Freiburg, Germany 5 years	76 patients 112 reconstructions 205 implants	Mix of single-crown reconstructions, splinted crowns and FPDs	Screw loosening: 7.1% Chipping: 5.4% (reconstruction level)

First author, year	Study design, setting and time of follow-up	Sample size	Type of reconstruction	Main findings
Simonis et al. (2010)	Retrospective University of Strasbourg, France 10-16 years	55 patients 131 implants	36 single-crown reconstructions 22 implant-implant FPDs	Total: 31.1% (reconstruction level)
Wennerberg and Jemt (1999)	Retrospective Specialist clinic, Gothenburg, Sweden 5 years	137 patients 422 implants	Implant-supported FPDs	Total: 47% Screw loosening: 13% Chipping: 14% (patient level)
Wittneben et al. (2014)	Retrospective University of Bern, Switzerland 10.75 years	303 patients 397 reconstructions 511 implants	268 single-crown reconstructions 127 FPDs	Screw loosening: 2.6% Chipping: 20.3% (reconstruction level)
Örtorp and Jemt (2009)	Retrospective Specialist clinic, Gothenburg, Sweden 15 years	65 patients 65 reconstructions	Full-jaw reconstructions in the mandible	Screw loosening: 3.1% Chipping: 46.2% (patient level)

Biological complications associated with implant-supported restorative therapy

Definitions of mucositis and peri-implantitis

Peri-implant mucositis has been described as 'an inflammatory lesion of the soft tissues surrounding an endosseous implant in the absence of loss of supporting bone or continuing marginal bone loss' (Heitz-Mayfield & Salvi, 2018). The condition is clinically detected through the presence of bleeding and/or suppuration on probing without progressive bone loss (T. Berglundh, Armitage, et al., 2018). Mucositis is considered the precursor of peri-implantitis (Jepsen et al., 2015) and if the condition is treated, peri-implantitis may be avoided.

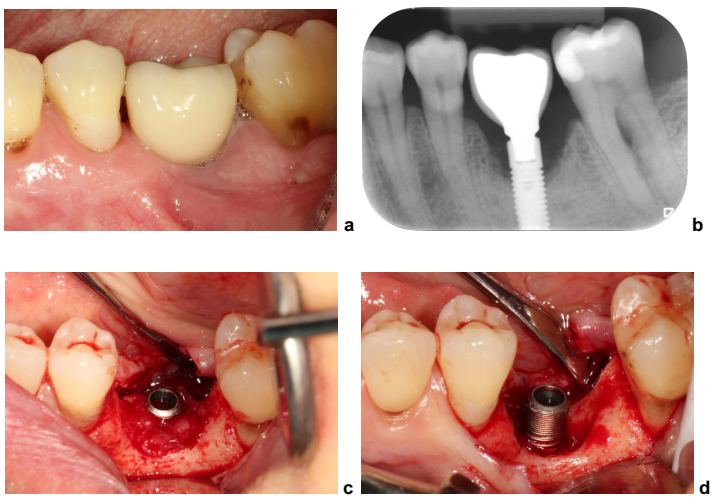


Figure 2 Implant regio 36 with a diagnosis of peri-implantitis.
a) clinical appearance **b**) radiographic appearance
c) after elevation of flap **d**) after removal of inflammation tissue

Peri-implantitis is characterized by inflammation in the surrounding tissues of the implant, in combination with bone loss (Schwarz, Derks, Monje, & Wang, 2018). Clinically, the condition is identified by gentle probing around

the implant to detect any bleeding on probing (BoP) and/or suppuration as well as increased probing depths in relation to previous examinations. These findings are to be combined with a radiographic examination. Progressive bone loss beyond the point of initial bone remodeling, in combination with BoP, is consistent with peri-implantitis (T. Berglundh, Armitage, et al., 2018). An example of an implant with a diagnosis of peri-implantitis is illustrated in Figure 2.

If peri-implantitis is left untreated, progression of disease with additional bone loss leading to implant loss may occur. While implant loss due to peri-implantitis is categorized as "late implant loss", implants that failed to integrate after installation are considered "early implant loss".

Studies evaluating peri-implantitis and implant loss

Several studies have reported on prevalence of peri-implantitis and the occurrence of implant loss. In Sweden, Roos-Jansåker et al. (2006) evaluated 294 patients treated at a specialist clinic and found 16% of patients to present with advanced peri-implantitis after a follow-up period of 9-14 years (BoP/SUP and ≥1.8 mm bone loss following 1st year of function, bone level located ≥3.1 mm apical to implant shoulder). The prevalence of peri-implantitis reported for the population in this thesis (n = 588) was 14.5% (BoP/PUS and bone loss >2 mm) (Derks et al., 2016a). Early implant loss (occurring before connection of the prosthetic reconstruction) was detected in 4.4% of patients, while late implant loss (after connection of the prosthetic reconstruction) was identified in 4.2% (Derks, Håkansson, Wennström, Tomasi, et al., 2015).

Studies originating from other countries have presented heterogeneous data on the prevalence of peri-implantitis. In a Japanese investigation, the prevalence of peri-implantitis was found to be at a similar level as reported in the aforementioned Swedish studies. A total of 15.8% of patients after a mean follow-up period of 5.8 ±2.5 years (case definition: BoP/PUS and >1 mm bone loss) suffered from peri-implantitis (Wada et al., 2019). Vignoletti et al. (2019) evaluated 237 patients in Italy after a mean observation period of 4.7 ±3.2 years and found 35% of patients to present with peri-implantitis (case definition: BoP/SUP and radiographic bone level ≥ 2mm apical of reference landmark). An even higher prevalence was reported by Romandini et al. (2021) who evaluated 99 patients in Spain and found 56.6% to exhibit peri-implantitis (case definition: BoP/SUP and ≥2 mm bone loss) after a mean period of 7.8 ±4.4 years. The authors also applied case definitions from the 2017 World Workshop classification (BoP/SUP and radiographic bone level ≥3 mm) (T. Berglundh, Armitage, et al., 2018) and reported on a prevalence of peri-implantitis of 23.2% of patients.

Pattern of progression of peri-implantitis

Progression of peri-implantitis is recognized through identification of bone loss as documented in radiographs. As incipient forms of the disease may be treated in order to prevent more advanced forms of peri-implantitis, early detection is relevant in predicting reliable treatment outcomes (Jepsen et al.,

2015; Ravida et al., 2020). An example of progressive bone loss at an implant site is illustrated in Figure 3.

Fransson et al. (2010) evaluated 182 patients with 419 implants to describe the pattern and severity of peri-implantitis-associated bone loss. A mean bone loss of 1.7 mm ±1.3 mm (after the first year of function) over a mean follow-up period of 11.1 years was identified. The progression of bone loss over time presented a non-linear and accelerating pattern. In all, 68% of the patients exhibited bone loss ≥1 mm during the study period.

Derks et al. (2016b), evaluated 53 patients with 105 implants diagnosed with peri-implantitis. Based on radiographs from a 9-year period, the onset of disease was estimated through statistical modelling. The selected implants demonstrated a mean bone loss of 3.5 ±1.5 mm during 9 years and the onset of peri-implantitis had, for the majority of implants (81%), already occurred by year 3. The pattern of bone loss over time was, again, found to occur in an accelerating pattern.

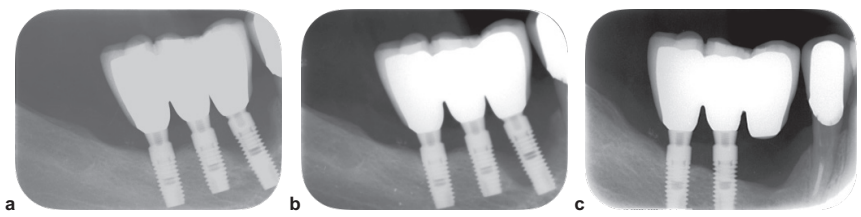


Figure 3 Radiographs at different time points. (a: 2012, b: 2015, c: 2017)

Table 4. Studies on progression of peri-implantitis

First author, year	Study design, setting and time of follow-up	Population	Method and case definition	Main findings
Derks et al. (2016b)	Retrospective Mix of general and specialist clinics, Sweden 9 years	53 patients 105 implants with ≥3 radiographs over the follow-up period	Radiographic assessment over time from 1 year after prosthesis connection to 9 years. Included patients with moderate/severe peri-implantitis defined as ≥1 implants with BoP/SUP and bone loss >2 mm.	Mean marginal bone loss 3.5 mm at 9 years. 31% of implants with >1 mm bone loss at year 2. 73% at year 5.
Fransson et al. (2010)	Retrospective Specialist clinic, Gothenburg, Sweden 5-23 years in function (mean 11.1 years)	182 patients (1070 implants) 419 implants with peri-implantitis associated bone loss -> 170 patients, 394 implants with radiographs including 1- or 2-year follow-up.	Radiographic assessment over time from year 1 after prosthesis insertion to end-point examination. Included patients with ≥1 implants with marginal bone level corresponding to ≥3 threads (a position located approximately 3 mm apical to the abutment-fixture junction) and detectable bone loss after the 1st year in function.	Mean marginal bone loss 1.68 ± 1.32 mm. 68% of implants with bone loss ≥1 mm. 32% of implants with bone loss ≥2 mm. 10% of implants with bone loss ≥3 mm.
Jemt et al. (2015)	Retrospective Specialist clinic, Gothenburg, Sweden Mean follow-up 11.1 + 9.1 years	Same study population as Fransson et al. (2010). 182 patients, 990 implants included-> 145 patients, 754 implants with measurable radiographs over the follow-up period.	Analysis of radiographs obtained at clinical examination after an additional ≥5 years of follow-up and the last radiographic examination available. Included patients with ≥1 implants with marginal bone level corresponding to ≥3 threads (a position located approximately 3 mm apical to the abutment-fixture junction) and detectable bone loss after the 1st year in function.	Mean marginal bone loss 0.3 mm. 8.6% of implants with annual bone loss >0.2 mm. 12% of implants with bone loss ≥1.8 mm.

Costs associated with dental implant therapy

As the number of patients treated with implant-supported restorative therapy is increasing on a global perspective, implant-related costs for stakeholders are bound to increase.

In Sweden, tooth replacement through the use of dental implants is reimbursed by the SSIA. Out of a total of 6.7 billion SEK of dental care subsidies in the adult population (about 4.2 million individuals) in 2019, 1.4 billion SEK were allocated to the initial implant-supported restorative therapy (SSIA 2021). Costs for maintenance care or complications related to additional treatment procedures required during follow-up, are not included in that amount. While the reimbursement system in Sweden is based on specific treatment codes, distinct treatment codes do not exist for all types of complications, Thus, additional costs cannot be evaluated through registry data alone.

In a review on economic evaluations in dental care by Eow et al. (2019), the majority of the included studies focused on cost-effectiveness in the field of caries prevention. The number of investigations on periodontal or implant therapy was limited (e.g. Fardal & Grytten, 2013; Jönsson, Öhrn, Lindberg, & Oscarson, 2012; Pretzl et al., 2009). At the EAO consensus conference in 2015 (Beikler & Flemmig) it was concluded that more economic evaluations were desirable to better assess the efficiency of implant-supported prostheses in various clinical situations.

Cost of complications

Although information on cost of complications in implant dentistry is scarce, there are studies that have explored the difference in cost-effectiveness between implant-supported and tooth-supported restorative therapy. Relevant studies typically compare different treatment procedures, two or more, to evaluate which is superior in terms of additional cost per improvement. Some authors have compared single implant treatment to 3-unit tooth-supported fixed dental prostheses (FDPs) (Brägger, Krenander, & Lang, 2005; Zitzmann, Krastl, Weiger, Kuhl, & Sendi, 2013), and there are other

investigations comparing more extensive therapies (Listl, Fischer, & Giannakopoulos, 2014; Zitzmann, Marinello, & Sendi, 2006).

In a comparison of single implant versus 3-unit FDPs, Zitzmann et al. (2013) presented results in favor of the implant-supported alternative as being the more cost-effective approach over a mean follow-up period of 4.1 years. Brägger et al. (2005) assessed 37 patients receiving tooth-supported 3-unit FDPs compared to 52 patients treated with implant-supported single crowns in a private practice. The authors concluded that costs for treatment owing to complications were similar between the two groups of patients, and that the implant-supported restorative therapy was more cost-effective in the short observation period of 1-4 years. Bouchard et al. (2009) took an entirely different approach to compare cost-effectiveness of implant- or tooth-supported restorative therapy as they estimated outcomes through modelling over a 20-year period. Six systematic reviews were used as data sources and the authors concluded from their statistical modelling that implant therapy was the superior choice of treatment, as it demonstrated higher success rates and lower overall costs. Kim et al. (2014) estimated cost-effectiveness over 10 years of implant-supported single crowns and 3-unit FDPs through modelling with data retrieved from a meta-analysis. Contrary to the other reports, the authors found that the implant-supported restorations were more costly than tooth-supported restorative therapy.

Table 5. Studies on cost-effectiveness in implant-supported restorative therapy

First author, year	Study design and setting	Population	Methods	Main findings
Bouchard et al. (2009)	Modelling of cost-effectiveness in implant-supported and tooth-supported restorative therapy over 20 years Paris, France	Data retrieved from 3 reviews on implant-supported restorative therapy and 3 reviews on tooth-supported restorative therapy	Decision trees designed as simulation models with 5-year intervals of treatment 'switching' when a patient experience complications	Lower cost and higher success rate for implant therapy over 20 years
Brägger et al. (2005)	Retrospective Private practice, Bern, Switzerland Follow-up range 1-4 years	37 patients restored with 41 3-unit FDPs 52 patients restored with 59 implant-supported single crowns (ISCs)	Economic evaluations of (i) preparatory treatment phase, (ii) initial reconstructive therapy and (iii) treatment of biological and/or technical complications thereafter	Costs for treatment of complications in the two groups were similar CHF 3 939 ±766 (FDPs) CHF 3 218 ±512 (ISCs)
Kim et al. (2014)	Modelling to estimate cost-effectiveness over 10 years Seoul, South Korea	Data on survival rates of implant-supported single crowns and 3-unit FDPs extracted from a meta-analysis	A decision tree designed to estimate cost-effectiveness	Implant-supported alternative cost $261-$342 more than tooth-supported 10.4% higher survival rate (implant-supported)
Zitzmann et al. (2013)	Prospective University, Basel, Switzerland Follow-up mean 4.1 years	15 patients restored with ISCs 11 patients restored with 3-unit FDPs	Preference trial, patient selected type of treatment after being informed. VAS used to score patients' satisfaction. Initial costs and maintenance costs (scheduled & unscheduled) recorded	Lower initial costs for ISCs which was main reason for higher probability of more cost-effective treatment with implant-supported single crowns Patient-perspective: equally satisfactory long-term results

Design of studies on implant therapy

The majority of studies on implant therapy have described implant survival and commonly used the implant as the unit of analysis as mentioned above. In addition, the majority of available and relevant studies are set in specialist and/or university clinics, hence describing efficacy of the provided therapy. One of the aims in this project was to describe outcomes in perspective of effectiveness, an attempt to assess care provided to patients in an everyday situation, as opposed to care provided under ideal conditions (efficacy) (T. Berglundh & Giannobile, 2013).

Aim and research questions

The aim of this research project was to evaluate the occurrence of complications in a population provided with implant-supported restorative therapy, and to further explore consequences and costs associated with the management of such complications.

The individual studies had specific aims, which focused on the following research questions:

Study I.
What is the occurrence, and what are the consequences of technical complications?

Study II.
What are the consequences of peri-implantitis, and what kind of therapy is provided to patients diagnosed with the disease?

Study III.
What is the overall occurrence of complications following implant therapy? Do the different types of complications occur independently or in clusters of patients?

Study IV.
What are the economic consequences of biological and technical complications?

Patients and Methods

Patients

The patient sample utilized in the present research project was based on and described in previously published studies by Derks et al. (2015; 2015; 2016a, 2016b).

Over 25 000 patients received reimbursement by the Swedish Social Insurance Agency (SSIA) for implant-supported restorative therapy in Sweden during the years 2003 and 2004. Out of roughly 23 000 patients in the age group 65 to 74 years, 3 000 patients were randomly selected, while all patients in the age group 45 to 54 years were included (n = 1 716). This resulted in a total sample of 4 716 patients. See Figure 4 for details on patient selection.

A questionnaire was sent to the initial population of 4 716 patients roughly six years after completion of the implant-supported therapy. The questionnaire contained items concerning the treatment the subjects had received, in addition to asking for consent for access to patient files. Specific information on the sort of questions and results in terms of patient-reported outcomes were previously described (Derks, Håkansson, Wennström, Klinge, et al., 2015). Out of 3 827 responders (81%), 3 107 patients provided their consent for patient file access.

Patients' caregivers were subsequently contacted and 2 765 patient files and radiographs were retrieved from more than 800 clinicians. For 89 patients, documentation in patient records was not readable and 10 patients had lost all implants prior to prosthetic loading. Following exclusion of these subjects, 2 666 patients provided with 3 781 reconstructions on 10 794 implants were included in **Study I**.

Out of the 2 666 patients, 900 were randomly selected and invited to a clinical examination in 2013 (9 years after initial restorative therapy). 596 patients

attended the clinical examination and 98 of these were diagnosed with moderate/severe peri-implantitis.

In 2017, the caregivers of the 98 patients diagnosed with moderate/severe peri-implantitis were again contacted by letter, asking for patient records and radiographs from the time period 2013 to 2017. During this period, 16 patients were deceased, dental caregivers of 11 patients did not respond and one patient refused participation. Consequently, **Study II** included 70 patients, who presented with a total of 338 implants at the examination in 2013.

Study III was based on the patient files and data obtained from the clinical and radiographic examination carried out in 2013 including 596 patients. In **Study IV**, evaluations of costs related to the implant-supported restorative therapy over a 9-year period were performed. Thus, 596 patient files were analysed with regard to initial restorative therapy, interventions associated with maintenance care as well as treatment procedures related to complications.

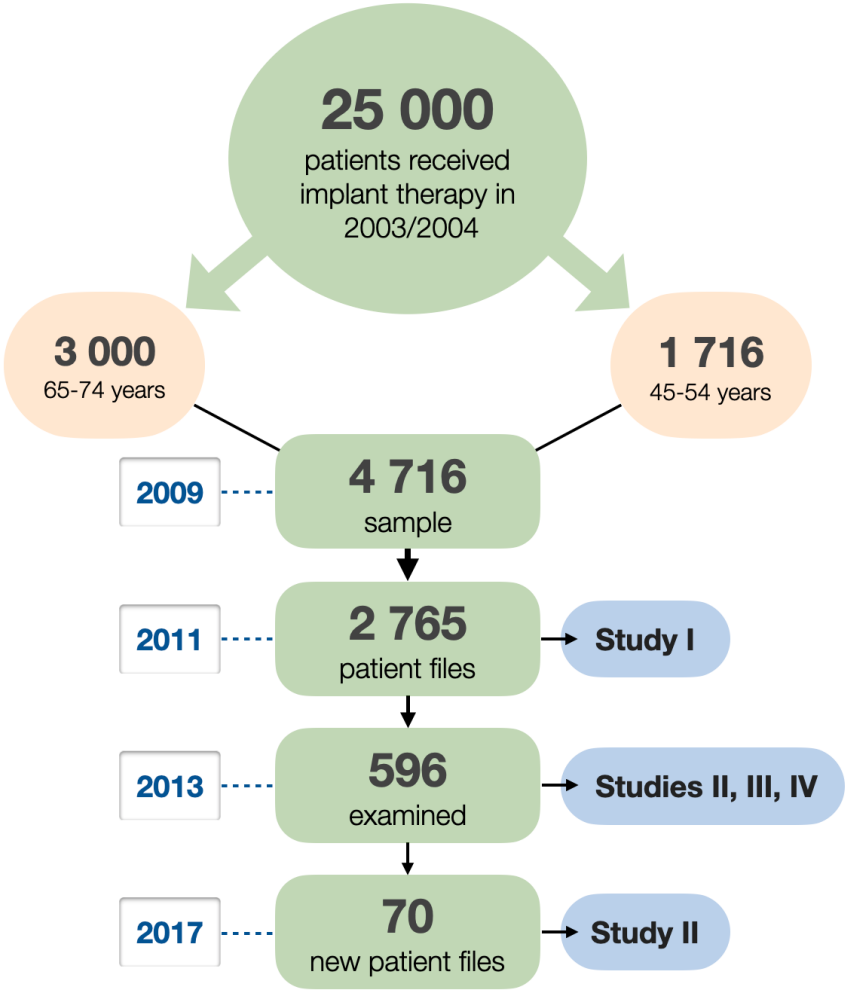


Figure 4 Flowchart of patients included in **Studies I, II, III** and **IV**

Ethical Considerations

All studies were approved by the regional Ethical Committee, Gothenburg, Sweden: **Studies I, III & IV** (Dnr 290-10), **Study II** (Dnr T1109-16). **Studies I, III & IV** were registered at clinicaltrials.gov (NCT01825772). For all studies, STROBE guidelines were considered. Patient consent was obtained prior to the collection of patient files in **Studies I, II, III and IV.**

Methods

Evaluation of patient files

Patient files were used to evaluate (i) technical complications, (ii) consequences of peri-implantitis and related treatment and (iii) preventive interventions and treatment procedures during follow-up.

In **Study I**, 2 666 patient files obtained from patients' caregivers in 2011 were analysed for any occurrence of technical complications related to the implant therapy performed in 2003. The period of follow-up in this evaluation was defined as the time from prosthesis delivery to the last date covered, as noted in the patient file.

A technical complication was defined as one of the following: screw loosening, decementation, chipping of acrylate/porcelain, fractures of framework, implants, abutments and misfit of the reconstruction. For chipping and loss of retention (screw loosening/decementation) we also recorded the time of event/s. Interventions required for the management of each complication were recorded and categorized as either chairside, repair by dental technician or complete renewal of reconstruction. The number of dental visits required for each event was noted.

In addition, background information such as gender and age of the patient was recorded. The caregivers providing the prosthetic therapy were categorized as either general or specialist clinicians. On implant level, location, diameter, length and brand were recorded. Data on type of retention, extent

and veneering material were recorded for all reconstructions. FileMaker Pro 16 Advanced (Claris International Inc., Cupertino, CA, USA) was used for data management, Figure 5.

Study III is based on data obtained from patient files described in **Study I**, and from the clinical examination in 2013, thus comprising 596 patients and their records.

The clinical examination in 2013 included assessments of probing pocket depths (PPD), bleeding on probing (BoP) as well as a radiographic examination. Preceding the examination, patients completed a questionnaire assisted by one of the examiners, all specialists in periodontics.

Patient files were also assessed for interventions associated with peri-implantitis during the follow-up period. Interventions were categorised as either non-surgical therapy, surgical therapy, or implant removal. Use of systemic antibiotics was noted. Type of clinician, dental hygienist or dentist, was recorded, as well as clinical setting.

In **Study IV**, we further analysed patient files from the 596 patients examined in 2013. Professional interventions, of preventive and reparative (biological and/or technical) nature, associated with the implant-supported restorative therapy were considered. Type of caregiver (dental hygienist/dentist, general/specialist), extent of therapy needed (dental hygienist/dentist/lab technician) and number of treatments were noted. Patient files of 514 individuals could be included.

Figure 5 Data collection using FileMaker

For **Study II**, additional information was collected as the caregivers, of the 98 patients identified with moderate/severe peri-implantitis at the clinical examination in 2013, were contacted. Patient records and radiographs subsequent to the clinical examination were requested, and 70 patient files could be retrieved. 16 patients were deceased, one patient did not wish to participate and 11 caregivers did not respond.

The 70 patients presented with 338 implants in 2013 and the mean (± SD) number of implants per patient was 4.8 ±2.5. At the clinical examination in 2013, an average of 0.8 ±1.2 implants per patient were diagnosed as healthy, 2.1 ±2.1 implants presented with peri-implant mucositis/mild peri-implantitis and 1.9 ±1.2 implant sites suffered from moderate/severe peri-implantitis. The criteria for the different diagnoses are shown in Table 6.

DIAGNOSIS	*Bleeding*	*Bone loss*
Healthy	No	None
Mucositis/mild peri-implantitis	Yes	≤ 2 mm
Moderate/severe peri-implantitis	Yes	> 2 mm

Table 6 Criteria for different diagnoses at implant sites at the examination in 2013

Assessment of radiographs

In **Study I**, information based on assessments of radiographs included number of crown units of the reconstructions, opposing dentition, and if applicable, cantilever extension. Measurements of the length of the cantilevers were performed using an image processing program, ImageJ (1.48a; Wayne Rasband, National Institutes of Health, Bethesda, MD, USA). The distance between the implant and the most distant aspect of the cantilever was measured. For calibration, either implant length, implant diameter or distance between thread peaks was used. The measurement process is illustrated in Figure 6.

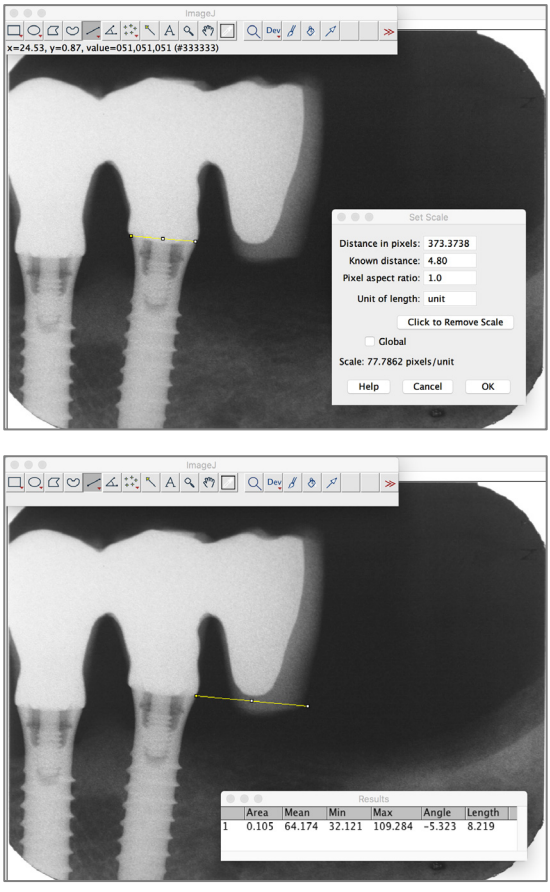
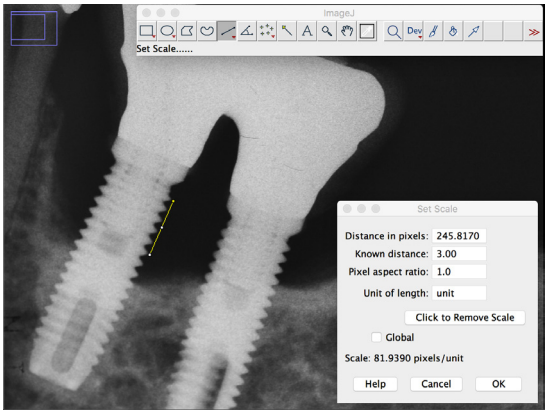
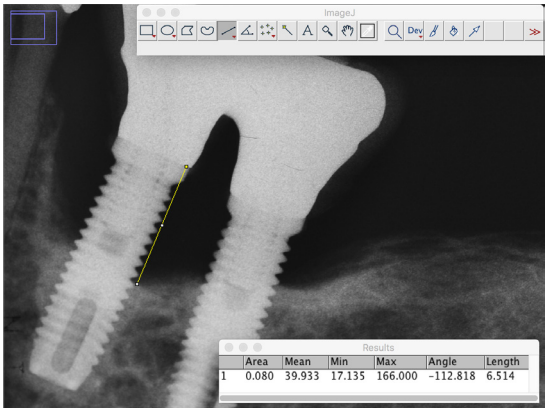


Figure 6 Pictures showing measurements on radiographs using ImageJ
a. Calibration measurement **b.** Measurement of cantilever length

Changes of the marginal bone levels were assessed in **Study II** using the same software program (ImageJ, 1.48a; Wayne Rasband, National Institutes of Health, Bethesda, MD, USA) as described in **Study I**. All radiographs depicting peri-implant marginal bone levels during follow-up were analysed. The distance between a reference point to the most apical level of the bone was recorded. Calibration of the image was executed using the same technique as described in **Study I**. Assessment of radiographic bone levels is illustrated in Figure 7.



a



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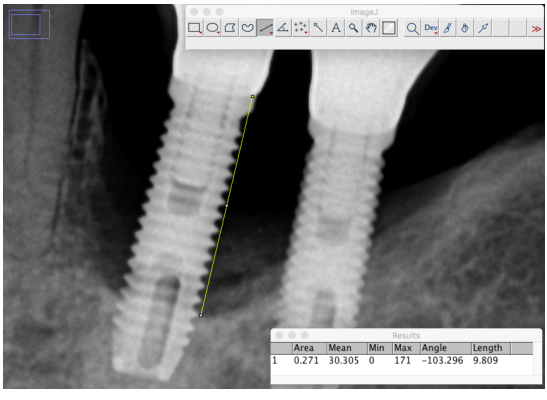

c

Figure 7 Example of radiographic measurements
a. Calibration
b. Measurement of bone level at the 9-year examination
c. Measurement of bone level at year 2014

Data analysis

In **Study I**, technical complications related to reconstructions were assessed on reconstruction and patient levels. Implants lost prior to loading were omitted as were zygomatic implants. All complications related to implants were evaluated on implant level.

Kaplan-Meier (SPSS24.0; SPSS Inc., Chicago, IL, USA) was used to evaluate the occurrence of technical complications over time. Technical complications in this assessment were divided into i) chipping or loss of retention, ii) chipping, and iii) loss of retention and estimated on reconstruction and patient levels. Risk indicators were identified for each type of complication, through adjusted Cox proportional hazard models using the reconstruction as the unit of analysis. Repeated events were also added using the mestreg function (Stata Statistical Software: Release 15, StataCorp LLC, College Station, TX, USA).

In **Study II,** Cox regression was used to identify predictors for additional bone loss subsequent to the clinical examination in 2013. Two thresholds for bone loss were used; 1.0 mm and 2.0 mm. The analyses were adjusted for periodontal status and smoking (Figure 5). Bone level changes were predicted through mixed linear modelling and included patient, implant and time. The impact of different diagnoses and clinical parameters as well as type and number of interventions were analysed in relation to bone level changes.

All analyses were performed on patient level in **Study III** using Stata (16.1; StataCorp LCC, College Station, TX, USA). Potential predictors of a complication was analysed using the stpm2 command with three degrees of freedom for flexible parametric modelling (Royston & Parmar, 2002) of survival and hazards. Time of event as well as repeated events were considered. Onset of peri-implantitis was determined as the time point of bone loss exceeding 1 mm. This time point was estimated based on baseline and follow-up radiographs evaluated by Derks et al. (2016a). A subgroup of patients (n=161) lacked baseline radiographs and in those cases a mean time of 5.3 years from accessible data was used. The questionnaire data was analysed through Pearson's chi-square testing.

For **Study IV**, a specific cost was assigned to every type of treatment provided to the patients during follow-up. Costs were based on reimbursement rates for 2021 provided by TLV, the Dental and Pharmaceutical Benefits Agency in Sweden. The initial cost of the implant-supported restorative therapy was also estimated, based on the extent of therapy as well as the clinical setting. An extra 30% was added to the cost for specialist care.

Accumulated costs were analysed at patient level over the observation period of 8.2 years. Costs were divided into three categories; total cost including initial therapy, additional treatment procedures related to complications alone and preventive measures alone. Cost was estimated over time using growth curve models. For each of the three categories of cost, adjusted linear models were generated. Results of the statistical modelling and the related code are illustrated in Figure 8.

The type of complication documented at the examination at 9 years, was used in an additional analysis to further estimate costs associated to different types of complications. Complications were categorised according to **Study III**: technical, peri-implantitis, implant loss, or combinations of complications.

AccCost_with	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
time	.5102962	.0715181	7.14	0.000	.3701232	.6504692
c.time#c.time	-.0000143	.0000164	-0.87	0.385	-.0000465	.0000179
Extent						
Partial	-4127.005	371.6754	-11.10	0.000	-4855.476	-3398.535
Single	-5926.047	486.6222	-12.18	0.000	-6879.809	-4972.285
Extent#c.time						
Partial	-.0910376	.0572259	-1.59	0.112	-.2031982	.0211231
Single	-.1745531	.0745873	-2.34	0.019	-.3207416	-.0283647
Extent#c.time#c.time						
Partial	.0000124	.0000135	0.91	0.360	-.0000141	.0000389
Single	.0000259	.0000172	1.51	0.132	-7.82e-06	.0000597
time	0	(omitted)				
No_implants_cat						
≥4 implants	3846.708	329.0676	11.69	0.000	3201.748	4491.669
No_implants_cat#c.time						
≥4 implants	.211351	.050339	4.20	0.000	.1126884	.3100136
No_implants_cat#c.time#c.time						
≥4 implants	-.0000532	.0000116	-4.58	0.000	-.000076	-.0000304
time	0	(omitted)				
Implant_Type						
Nobel	-683.7615	272.4099	-2.51	0.012	-1217.675	-149.8479
Astra	-197.6922	322.0271	-0.61	0.539	-828.8537	433.4693
Other	-387.7937	419.1076	-0.93	0.355	-1209.23	433.6421
Implant_Type#c.time						
Nobel	.0863735	.0414631	2.08	0.037	.0051072	.1676398
Astra	.2776706	.048615	5.71	0.000	.182387	.3729543
Other	-.0070222	.0640086	-0.11	0.913	-.1324767	.1184323
Implant_Type#c.time#c.time						
Nobel	-.0000313	9.40e-06	-3.33	0.001	-.0000497	-.0000129
Astra	-.0000604	.000011	-5.51	0.000	-.0000819	-.0000389
Other	-9.47e-06	.0000146	-0.65	0.516	-.000038	.0000191
time	0	(omitted)				
ClinPerio						
Perio	-176.6226	274.2111	-0.64	0.520	-714.0666	360.8213
No teeth	2305.403	382.3451	6.03	0.000	1556.02	3054.785
ClinPerio#c.time						
Perio	-.0057002	.0413568	-0.14	0.890	-.0867579	.0753576
No teeth	-.1254862	.0585524	-2.14	0.032	-.2402468	-.0107255
ClinPerio#c.time#c.time						
Perio	.0000234	9.29e-06	2.52	0.012	5.23e-06	.0000416
No teeth	.0000469	.0000135	3.47	0.001	.0000204	.0000734
_cons	7891.453	470.1284	16.79	0.000	6970.018	8812.888

```
mixed AccCost_with c.time##c.time##i.Extent c.time##c.time##i.No_implants_cat c.time##c.time##i.Implant_Type
c.time##c.time##i.ClinPerio|| LopNr: time, cov(unstr) mle
```

Figure 8 Final statistical model, Study IV. Coding as seen above.

Results

Study I

Technical complications following implant-supported restorative therapy performed in Sweden

Occurrence of technical complications

Nearly one out of four patients (24.8%) experienced at least one technical complication during the mean observation period of 5.3 years. The corresponding figure at reconstruction level was 20.2%.

Chipping was the most common technical complication and occurred at 11.0% of the reconstructions, followed by screw loosening (9.1%), and decementation (5.9%). A total 53.3% of affected patients experienced repeated occurrence of a technical complication. Four or more technical complications were noted for 19.4%. Fractures of implants or abutments were rare events. All types of technical complications and their occurrence are presented in Table 7.

Patients	660 out of 2,666 (24.8%) patients affected by at least one technical complication					
	Decementation in 960 patients with cemented reconstructions	**Screw loosening** in 1.817 patients with screw-retained reconstructions	**Screw fracture** in 1,817 patients with screw-retained reconstructions	**Framework fracture** in 2,666 patients	**Misfit** in 2,666 patients	**Chipping** in 2,666 patients
	66 (6.9%)	205 (11.3%)	19 (1.0%)	24 (0.9%)	32 (1.2%)	377 (14.1%)
Reconstructions	764 out of 3,781 (20.2%) reconstructions affected by at least one technical complication					
	Decementation in 1,211 cemented reconstructions	**Screw loosening** in 2,514 screw-retained reconstructions	**Screw fracture** in 2,514 screw-retained reconstructions	**Framework fracture** in 3,781 reconstructions	**Misfit** in 3,781 reconstructions	**Chipping** in 3,781 reconstructions
	72 (5.9%)	228 (9.1%)	20 (0.8%)	24 (0.6%)	34 (0.9%)	417 (11.0%)
Implants	38 (0.35%) out of 10,794 implants affected by at least one complication					
	Implant fracture		**Abutment fracture**		**Abutment loosening**	
	4 (0.037%)		9 (0.083%)		25 (0.23%)	

Table 7 Technical complications (n=2 666 patients; n=3 781 reconstructions; n=10 794 implants).

Dental visits in relation to technical complications

The majority of patients experiencing a technical complication had at least one intervention reported (97%). The range of number of dental visits related to the complication was 1-33 with a mean number of 3.9 visits.

Technical complications in 338 patients were handled chair-side by a dentist, while reparative measures by dental technicians were required for 204 patients. Complete renewal of the reconstructions was performed for 39 patients (Figure 9).

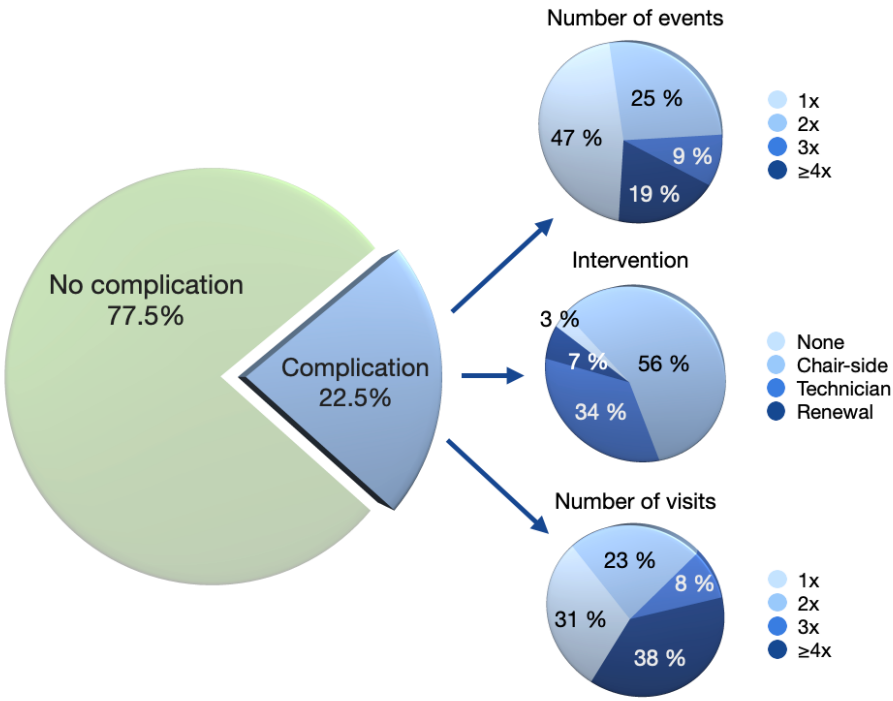

Figure 9 Proportion of patients with ≥1 technical complication. Chipping and/or loss of retention are considered.

Risk indicators for technical complications

The more extensive implant-supported reconstructions had the highest overall risk for technical complications, while the smaller ones had a generally lower risk for such an event. Hence, the extent of the reconstruction was a risk indicator for a technical complication. For further details, see Table 8.

Observing the types of complications separately, chipping was more common for the larger reconstructions as well as for reconstructions with cantilevers. Chipping was also more frequent in the mandible compared to the maxilla, and was also more often noticed when the opposing dentition carried natural teeth compared to removable dentures. Male patients had a higher risk for chipping of their reconstructions.

Loss of retention occurred more frequently for smaller reconstructions as well as for those with cantilevers. Loss of retention was less common for reconstructions connected to Nobel Biocare implants compared to other implant brands. There was an overall greater risk for technical complications for implant-supported reconstructions delivered by specialist dentists compared to general dentists.

		Hazard Ratio	95% CI	p-value
Extent	Full-jaw	1	-	-
	Partial-jaw	0.51	0.39 – 0.68	0.000
	Single-tooth	0.42	0.26 – 0.66	0.000
Retention	Cemented	1	-	-
	Screw-retained	1.76	1.31 – 2.36	0.000
Cantilever	No	1	-	-
	Yes	1.64	1.26 – 2.14	0.000
Jaw	Maxilla	1	-	-
	Mandible	0.77	0.64 – 0.93	0.006
Opposing dentition at loading	Natural dentition	1	-	-
	Tooth-supported prosthodontics	1.27	0.98 – 1.64	0.076
	Implant-supported prosthodontics	1.26	0.95 – 1.66	0.103
	Implants and teeth	1.24	0.88 – 1.75	0.219
	Removable	0.28	0.15 – 0.50	0.000
Implant brand	Nobel Biocare	1	-	-
	Astra Tech	1.37	1.08 – 1.73	0.008
	Straumann	1.30	1.59 – 1.60	0.017
	Other	0.91	0.66 – 1.25	0.560
Clinician - Prosthetics	General practitioner	1	-	-
	Specialist	1.41	1.15 – 1.73	0.001

Table 8 Risk indicators for technical complications – Chipping and/or loss of retention
Hazard ratios and 95% confidence intervals (CI) are based on a mixed-effects regression model (Weibull PH) using the mestreg command in Stata.

Study II

Interventions for peri-implantitis and their effects on further bone loss: A retrospective analysis of a registry-based cohort.

Disease progression

The mean bone level change during the observation period was -0.83 ±1.2 mm at patient level. The corresponding figure at the implant level was -0.74 ±1.5 mm. 21 of 63 patients (33.3%) had ≥1 implant site with bone loss >2 mm. 34 implant sites out of 282 presented with bone loss >2 mm (12.1%).

According to peri-implant diagnosis at the clinical examination in 2013, Group A (absence of bleeding on probing), showed a mean bone level change of -0.46 ±0.9 mm. 1 implant site (2.1%) in this group presented with bone loss >2 mm. For Group B (presence of BoP and bone loss ≤2 mm at the examination), the mean bone level change was -0.53 ±1.0 mm and 11 sites (9.1%) presented with >2 mm bone loss. For Group C (BoP and bone loss >2 mm at the examination), the mean bone level change was -1.09 ±2.0 mm and 22 sites (19.6%) displayed bone loss >2 mm (Figure 10).

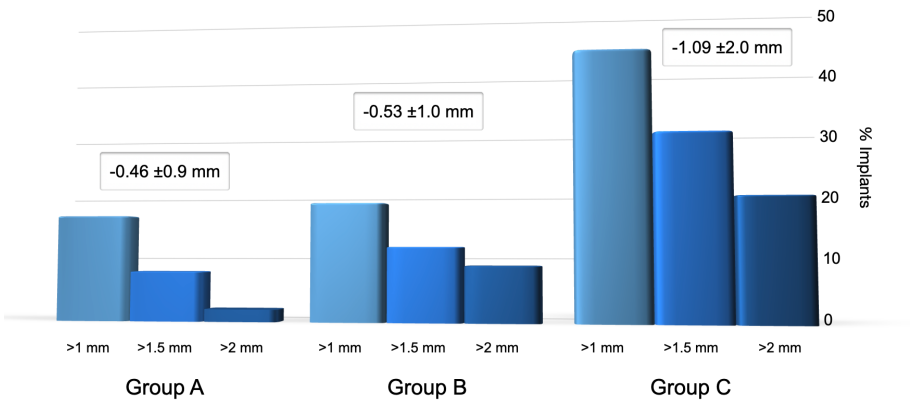

Figure 10 Changes of marginal bone levels from 2013 to 2017 according to peri-implant status in 2013 (Group A: absence of BoP, Group B: presence of BoP and bone loss ≤2 mm, Group C: presence of BoP and bone loss >2 mm) 12 implants lost, all in group C

Predictors for further bone loss are presented in Figure 11. The strongest predictor for bone loss ≥1 mm was suppuration after probing (HR 3.2) while the strongest predictor for bone loss ≥2 mm was bleeding on probing at three or four sites (HR 7.1).

Bleeding on probing, probing depths and implant group (A-C) were detected as significant predictors for bone level change through linear mixed modelling.

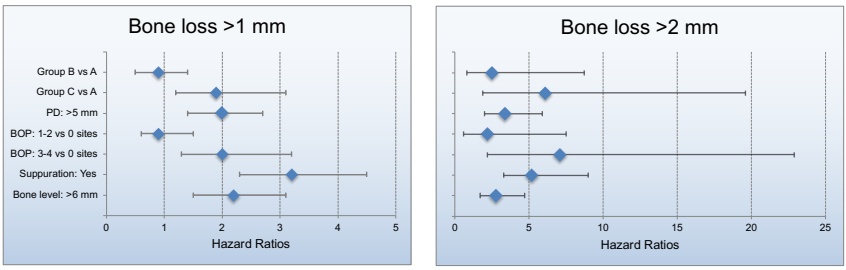

Figure 11 Cox regression. Outcome: Bone loss by threshold (2013-2017)
Group A: absence of BoP
Group B: presence of BoP and bone loss ≤2 mm
Group C: presence of BoP and bone loss >2 mm (at examination in 2013)

Professional intervention

63 out of the 70 patients received treatment for peri-implantitis and the mean number of visits was 9.5 ±5.4 during the mean follow-up of 3.3 years. There was an equal amount of visits to dental hygienists (4.8 ±4.9) and dentist (4.8 ±3.5).

All 63 patients received non-surgical therapy, while 17 were also treated with peri-implant surgery. There was a variation of methods used for the non-surgical therapy.

76% of the patients were treated in general practice while the rest was treated at specialist clinics. 77% of the patients receiving surgical therapy were treated in a specialist setting. A variety of methods were also applied during surgery. Cleaning of implant surfaces was performed, in the majority of cases by hand, or by a combination of hand instruments, titanium brush, and ultrasonic instruments.

Peri-implant surgery was performed 429 ±407 days subsequent to diagnosis. The average additional bone loss prior to surgery amounted to 1.4 ±2.4 mm. In the time period after surgical intervention (1,237 ±440 days) a mean bone loss of 0.2 ±1.0 mm was detected (Table 9 & Figure 12).

Surgically treated implants				**No surgical therapy**				
Days from diagnosis to surgery mean: 429 ±407	-1.40 ±2.40 mm n = 42 implants			**Observation period mean: 1,302 ±435 days**	-0.55 ±1.06 mm n = 240 implants			
	Group A n = 3	Group B n = 6	Group C n = 33		Group A n = 45	Group B n = 115	Group C n = 79	not probable n = 1
	-0.72 ±1.11 mm	-1.63 ±2.07 mm	-1.42 ±2.56 mm		-0.46 ±0.87 mm	-0.44 ±0.87 mm	-0.76 ±1.35 mm	-0,79 mm
Days following surgery mean: 1,237 ±440	-0.15 ±0.96 mm n = 30 implants							
	Group A n = 3	Group B n = 3	Group C n = 24					
	-0.09 ±0.94 mm	0.07 ±0.67 mm	-0.19 ±1.02 mm					
±: Standard deviation **Group A:** Absence of bleeding on probing (BOP) *(at examination 2013).* **Group B:** Presence of BOP and bone loss ≤2 mm *(at examination 2013).* **Group C:** Presence of BOP and bone loss >2 mm *(at examination 2013).*								

Table 9 Surgical therapy and bone level changes from 2013-2017 (implant level, n=282)

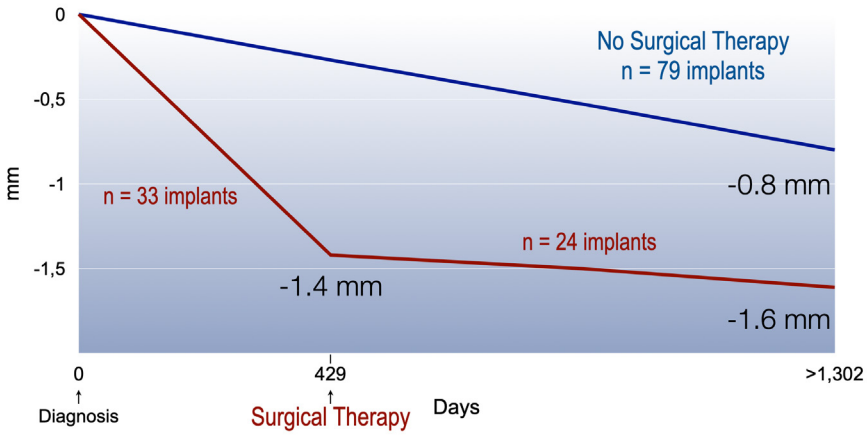

Figure 12 Bone levels before and after surgical intervention

Study III

Occurrence and clustering of complications in implant dentistry

42% of the 596 patients were affected by at least one complication during the follow-up period of 8.9 ±0.8 years. 26% of all patients experienced an event related to a technical complication which was the most frequent type of complication. For 19% of patients, peri-implantitis was recorded and 41% of these also experienced another type of complication. 8% of the participants experienced implant loss and 52% of these presented with an additional type of complication (Table 10).

Type of complication	n = 596	
Technical	155	26.0%
Peri-implantitis	110	18.5%
Implant loss	45	7.6%
Free of any complication	345	57.9%

Table 10 Occurrence of different types of complications

Technical complications were the most frequently occurring type of complications and were observed mostly independently. Biological complications occurred in a more overlapping pattern.

Technical complications as well as implant loss mostly occurred within the first year of function. The highest predicted hazards for those types of complications were detected at 0.7 years and 0.2 years, respectively. For peri-implantitis the pattern of the predicted hazard had a more even outline with no clear peaks during the observation period. For 50% of patients experiencing a complication, the first related event had occurred within the initial 2.4 years of follow-up. The extent of restorative therapy, as well as a

diagnosis of periodontitis at the 9-year examination, were identified as statistically significant risk factors for the occurrence of a complication (Table 11).

		Hazard Ratio	Confidence Interval (95%)	p-value
Extent of implant therapy	Single-tooth	1		
	Partial-jaw	2.47	1.64-3.70	<0.001
	Full-jaw	3.92	2.50-6.15	<0.001
Periodontitis diagnosis (9y examination)	No	1		
	Yes	1.56	1.17-2.07	0.003
	Edentulous	1.16	0.79-1.71	0.435

Table 11 Results of survival modelling for complications over the 9 years of follow-up displaying statistically significant predictors. Hazard ratios and 95% confidence intervals are based on a mixed-effects regression model (Weibull PH) using the mestreg command in Stata.

95% of patients were satisfied with their implant-supported restorative therapy at the 9-year examination. Patients experiencing a complication were more likely to report on discomfort from their implants. Details on patient-reported outcomes are described in Table 12.

All subjects (n=596)		Complications				
		Yes (n=251)				No (n=345)
Percentage of subjects satisfied with implant therapy at 9y examination	95%	92%				97%
		Technical complications alone (n=115)	Peri-implantitis alone (n=65)	Implant loss alone (n=17)	Combination (n=54)	
		94%	94%	82%	89%	
Percentage of subjects reporting discomfort from their implants during the study period	29%	42%				19%
		Technical complications alone (n=115)	Peri-implantitis alone (n=65)	Implant loss alone (n=17)	Combination (n=54)	
		37%	32%	35%	67%	
Percentage of subjects reporting a technical complication during the study period	20%	34%				10%
		Technical complications alone (n=115)	Peri-implantitis alone (n=65)	Implant loss alone (n=17)	Combination (n=54)	
		41%	12%	18%	48%	
Percentage of subjects reporting on inflammation around implants during the study period	17%	23%				12%
		Technical complications alone (n=115)	Peri-implantitis alone (n=65)	Implant loss alone (n=17)	Combination (n=54)	
		9%	31%	24%	44%	
Percentage of subjects reporting that they would choose implant therapy again	92%	87%				96%
		Technical complications alone (n=115)	Peri-implantitis alone (n=65)	Implant loss alone (n=17)	Combination (n=54)	
		90%	85%	88%	80%	

Table 12 Patient-reported outcomes in relation to complication during the 9-year follow-up period

Study IV

Health economic aspects of implant-supported restorative therapy

The mean follow-up period was 8.2 ±1.1 years and the mean number of preventive measures and treatment procedures was 12.2 during that period (preventive measures mean: 10.1 ±5.0 and treatment procedures mean: 2.1 ±4.2).

Estimated costs for treatment

The estimated mean cost for the initial restorative therapy amounted to 6,767 US dollars (95%CI; 6,519-7,015). The corresponding figure at the end of the observation period was 8,229 US dollars (95%CI; 7,965-8,491), thus presenting an increase in cost of 1,462 US dollars (95%CI; 1,387-1,536). The mean total cost for full-jaw restorations was 11,724 US dollars (95%CI; 11,144-12,304) compared to that of 2,380 US dollars (95%CI; 1,719-3,041) for single-tooth restorations.

The calculated mean cost for preventive measures was 1,063 US dollars (95%CI; 1,027-1,099) over the follow-up period. The only significant factor associated with higher preventive costs was clinical setting with care provided in a private setting which was 94 US dollars (95% CI; 9-179) more costly when compared to public dental care.

The mean cost for additional treatment, predicted for the group of patients requiring additional therapy (n=253), was 794 US dollars (95% CI; 677-912) per patient. Significant differences were noted for the extent of the initial restorative therapy, where full-jaw-restored patients generated a cost of 1,113 US dollars (95% CI; 888-1,338) compared to single-tooth restored-patients (479 US dollars (95% CI; 47-910)). Details on costs are displayed in Figures 13 & 14.

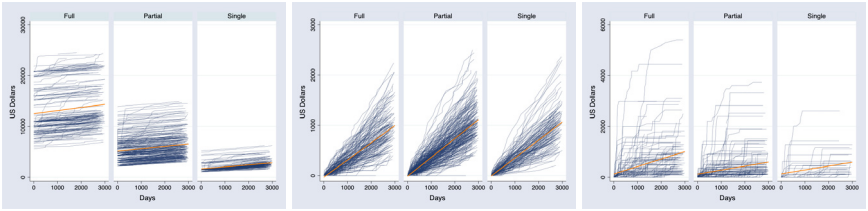

Figure 13 Graphs by extent of reconstruction (full-jaw, partial-jaw & single-tooth). Observed cost per patient over time (blue lines) and predicted cost (orange line)
a all costs
b preventive measures
c treatment procedures, only patients with at least one treatment procedure considered

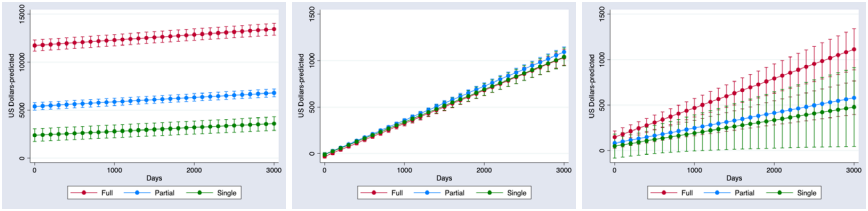

Figure 14 Predictions of costs Prediction with 95% confidence intervals based on fully adjusted linear models (n=514).
a all costs
b cost for preventive measures
c cost for treatment procedures, only patients with at least one treatment procedure considered (n=253)

Estimated costs by type of complication

The highest additional costs were detected for patients experiencing implant loss (2,403 US dollars, 95% CI; 1,971-2,835) followed by combinations of different complications (2,347 US dollars, 95% CI; 2.132-2,562). The cost for technical complications and peri-implantitis were similar at 1,614 US dollars (95% CI; 1,455-1,772) and 1,619 US dollars (95% CI; 1,410-1,828) respectively. Differences between categories of complications are presented in Figure 15 & 16.

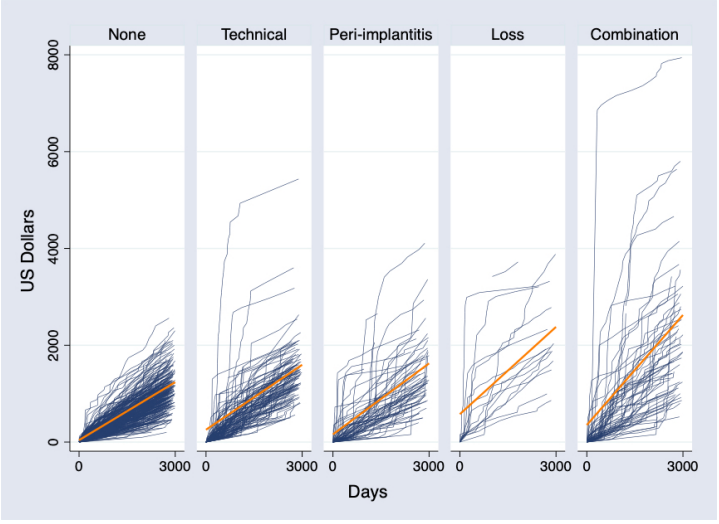

Figure 15 Observed (blue lines) and estimated costs (orange lines) of additional interventions per patient over time by complication status. Predictions are based on a linear model.

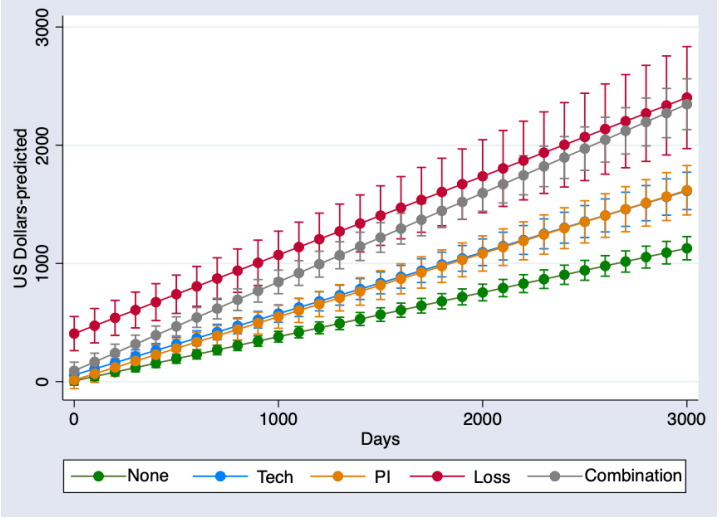

Figure 16 Predictions of costs of additional interventions including 95% confidence intervals based on an adjusted linear model.

Main findings

- Biological and technical complications following implant-supported restorative therapy were common. Extent of the reconstruction and history of periodontitis were identified as risk indicators. (**Study III**)

- The risk for technical complications was highest during the first year of follow-up and professional intervention was often required. (**Studies I & III**)

- The risk for peri-implantitis was constant over the entire follow-up period, while the risk for implant loss and technical complications peaked early and decreased later during follow-up. (**Study III**)

- Technical complications occurred in an isolated pattern, while peri-implantitis and implant loss showed clustering with other types of complications. (**Study III**)

- In cases of advanced peri-implantitis, non-surgical interventions were not sufficient in arresting the disease, whereas surgical interventions supressed disease progression. (**Study II**)

- Additional costs during follow-up were related to the extent of the initial restorative therapy. Implant loss was the most costly type of complication. (**Study IV**)

Concluding remarks

The major part of information in this project was based on patient files. In **Study I**, patient files were assessed for any technical complication related to implant-supported restorative therapy. In **Studies II**, **III** and **IV** patient files were further evaluated for information on the type of dental care patients had received during follow-up. Radiographic measurements were performed in **Studies I**, **II** and **III**.

The statistical methods in the different parts of the project were similar. For most evaluations, the patient was the unit of analysis as has been recommended (Tonetti & Palmer, 2012). Data presentation on the patient level was judged to be clinically relevant and also avoids the problem of data clustering. As for unit of analysis, however, there were some exceptions. In **Study II**, marginal bone levels were assessed and data were reported on implant level. In **Study I**, addressing technical complications, the implant-supported restoration was used as the unit of analysis.

Technical complications associated with implant-supported restorative therapy

The results in **Study I** showed that one out of four patients and one out of five reconstructions demonstrated at least one technical complication. This is similar to data reported by Wittneben et al. (2014), who presented corresponding figures for reconstructions with a technical complication of 25%. The proportion of reconstructions presenting with chipping was 20%.

Chipping was even more common in a study by Örtorp and Jemt (2009), who presented a figure of 46% of patients compared to 14% of patients as reported in **Study I**. The variations might be explained by the different materials used in reconstructions as the restorations included in the report by Örtorp and Jemt (2009) were exclusively full-arch bridges with acrylic teeth.

Kreissl et al. (2007), on the other hand, evaluated patients with single-tooth and partial-jaw reconstructions and reported on a considerably lower

percentage (5%) of reconstructions demonstrating chipping. Our findings demonstrated that the extent of the reconstruction was a risk indicator for chipping. Furthermore, the follow-up period in the study by Kreissl et al. (2007) was limited to 5 years. It has been reported that technical complications occurred more frequently subsequent to a function time of 5 years (Dierens et al., 2016).

Interestingly, in another Swedish study (Adler et al., 2020), chipping occurred for 7% of patients, half of what was reported in **Study I**. The reconstructions in that study were a combination of single crowns, partial, and full-jaw restorations. The material of the reconstructions was not reported. In this context, a limitation of the present data is the absence or sparse information on the material used in the FDPs. This limitation prevented analysis of potential confounding.

Thus, varying results presented in different studies may be explained by a mixture of type and material of reconstructions included, as well as different periods of follow-up. The setting in all studies mentioned were either specialist or university clinics, which is in contrast with the data in this thesis including information from a variety of different clinics. However, the different settings are not clearly reflected in numbers of patients affected by technical complications.

Risk factors for technical complications

The strongest risk indicator for technical complications in **Study I** was the extent of the reconstruction. This is in line with data presented by Wittneben et al. (2014), who demonstrated that multiple-unit reconstructions had higher rates of chipping compared to single crowns. The authors did not find that cantilevered reconstructions showed higher rates of chipping than those without, as we could recognize in **Study I**. However, there were no full-jaw restorations included in the study by Wittneben et al (2014).

Bruxism has earlier been presented as a risk factor for technical complications (Chrcanovic et al., 2020c; Wittneben et al., 2014). As data in this thesis were

based on patient files, information on bruxism could not be retrieved and hence, not evaluated, which is a further limitation related to **Study I**.

In contrast to data in **Study I**, and other reports, Adler et al. (2020) could not identify any predictors for technical complications. One potential explanatory factor could be that only minor technical complications were observed in that investigation.

Complications of tooth-supported fixed dental prostheses

It is interesting to note that one out of four patients experienced a technical complication in **Study I**, which is similar to figures presented in analyses on tooth-supported restorative therapy (Pjetursson et al., 2015). Similar to implants, also biological complications may occur at tooth-supported restorations. These include caries, loss of vitality and periodontitis (Brägger et al., 2011; De Backer, Van Maele, De Moor, & Van den Berghe, 2008; Decock, De Nayer, De Boever, & Dent, 1996; Karlsson, 1989).

Biological complications associated with implant-supported restorative therapy

In **Study III** the patient category diagnosed with peri-implantitis were observed to significantly overlap the subgroup of patients experiencing implant loss. Data from **Study II** showed that the implants that were lost during the follow-up of 3.3 years following the clinical examination had all been diagnosed with moderate/severe peri-implantitis at the examination. No implant loss occurred in the categories peri-implant health or peri-implant mucositis.

Peri-implantitis

The case definition of peri-implantitis in **Studies II, III, IV** was presence of bleeding on probing and bone loss >2 mm, thereby corresponding to advanced forms of the disease. This does not reflect the more general forms

of peri-implantitis. Several studies have reported on prevalence of peri-implantitis, presenting various results (Derks & Tomasi, 2015). The differences may be explained by diverse case definitions of peri-implantitis, as well as different lengths of follow-up and clinical setting.

It was stated at the most recent World Workshop on peri-implant diseases and conditions (T. Berglundh, Armitage, et al., 2018), that a diagnosis of peri-implantitis in epidemiological studies requires presence of bleeding, and/or suppuration on gentle probing in combination with increased probing depths compared to previous examinations. In addition, bone loss beyond levels resulting from initial bone remodeling should be evident. In the absence of baseline radiographs, bone levels ≥3 mm apical of the most coronal portion of the intra-osseous part of the implant should be considered.

As it has been demonstrated earlier, using the proposed case definition in the case of missing baseline information would not identify patients with incipient peri-implantitis (Romandini, Berglundh, Derks, Sanz, & Berglundh, 2021). Baseline documentation is fundamental for early diagnosis of the disease.

In **Study II**, the occurrence of additional bone loss of >2 mm at implants previously diagnosed with peri-implantitis was 20% over the mean observation period of 3.3 years. This finding is in contrast with corresponding data of 12% reported in a 9.1-year observational study by Jemt et al. (2015). The varying results may be partly explained by differences in implant surface characteristics between the two study samples. While the implants analyzed in **Study II** had different types of modified surfaces, the implants in the study by Jemt et al. (2015) had non-modified, turned surfaces. It has been demonstrated, both in preclinical studies (Albouy, Abrahamsson, & Berglundh, 2012; Carcuac et al., 2013) and clinical trials (Carcuac, Derks, Abrahamsson, Wennström, & Berglundh, 2020) that the amount of bone loss during progression of peri-implantitis varies depending on implant surface characteristics.

Management of peri-implantitis

Results from **Study II** indicated that treatment of peri-implantitis was offered to virtually all patients diagnosed with advanced peri-implantitis. This treatment however, rarely included surgical modalities. Instead, non-surgical therapy was provided, often repeatedly. This is noteworthy as the literature clearly showed that non-surgical treatment is not sufficient in arresting progression of advanced peri-implantitis (Faggion, Listl, Fruhauf, Chang, & Tu, 2014).

Several studies have demonstrated the impact of supportive care in maintaining peri-implant health and preventing peri-implantitis following dental implant therapy (Costa et al., 2012; Roos-Jansåker et al., 2006) as well as after peri-implantitis surgery (Heitz-Mayfield et al., 2018; Serino, Wada, Mameno, & Renvert, 2021). The investigations demonstrated similar results and reached the conclusion that regular supportive maintenance care is essential in the preservation of healthy tissues around implants. In addition, Schwendicke et al. (2015) concluded that providing supportive care to patients treated with implant-supported restorative therapy, prevented or delayed peri-implant disease which was proven to be cost-effective.

Moreover, several studies have evaluated the impact of surgical therapy on the progression of peri-implant disease (T. Berglundh, Wennström, & Lindhe, 2018; Carcuac et al., 2020; Roccuzzo, Pittoni, Roccuzzo, Charrier, & Dalmasso, 2017; Schwarz, John, Schmucker, Sahm, & Becker, 2017; Serino & Turri, 2011). Namely, anti-infective approaches were effective in arresting peri-implantitis associated bone loss.

Interestingly, the 17 patients who received surgical intervention in **Study II**, showed only minor bone alterations (-0.15 ±0.96 mm) after surgical therapy. Before surgery, however, a mean bone loss of -1.40 ±2.40 mm was noted during a considerably shorter period of time, 429 ±407 days, than the mean follow-up time of 1 237 ±440 days following surgery.

This observation corresponds well with results from Schwarz et al. (2017), who evaluated 15 patients diagnosed with advanced peri-implantitis (PPD >6 mm, intrabony component >3 mm and supracrestal component >1 mm)

after surgical therapy. Distinct reductions in BoP and PPD as well as CAL gain at treated implant sites were reported. The clinical improvements along with tissue stability could be maintained in the long-term.

Implant surface

In a study by Jemt et al. (2015), peri-implantitis surgery was observed to be more frequently performed at implants with modified surfaces when compared to machined (non-modified) surface implants. This observation corresponds well with other clinical studies evaluating the effect of peri-implantitis surgery.

Treatment outcomes (reduction of PPD, BoP as well as bone level preservation) were superior at non-modified surface implants compared to modified-surface implants, as observed in an evaluation of implants following surgical therapy (T. Berglundh, Wennström, et al., 2018). Carcuac et al. (2020) in a 5-year follow-up evaluation of patients treated surgically for advanced peri-implantitis also reported that implants with a modified surface were at higher risk for recurrence of disease following surgery compared to implants with non-modified surfaces (OR 5.1, 95%CI 1.6-16.5).

Corresponding evaluations could not be performed in this retrospective analysis as most implants included were rough-surfaced implants. Furthermore, only 17 out of 63 patients received peri-implant surgery, which is quite a small number of patients. However, one of the strengths in **Study II** is that the evaluations made would not be possible to execute in a prospectively designed investigation, as it would not be ethically correct to deny patients diagnosed with moderate/severe peri-implantitis adequate therapy over longer observation periods.

Peri-implantitis and Implant loss

In **Study II** 12 implants were lost during a follow-up of 3.3 years. All lost implants were initially affected by moderate/severe peri-implantitis. No implant loss, however, occurred among those classified as healthy or mild peri-implantitis. **Study III** further underlined the association between peri-

implantitis and implant loss as there was a significant overlap of the two complications. In other words, patients exhibiting peri-implantitis were overrepresented among those suffering implant loss. Several other studies have reported on implant loss as a result of peri-implantitis (e.g. Buser et al., 1997; Daubert, Weinstein, Bordin, Leroux, & Flemming, 2015; Dvorak et al., 2011; Romeo et al., 2004).

Predictors for disease progression

Results from **Study II** showed that the following parameters were indicative of future disease progression; a diagnosis of moderate/severe peri-implantitis, suppuration on probing, bleeding on probing at 3-4 aspects and peri-implant pocketing ≥6 mm.

These data are in line with results from other clinical studies. Carcuac et al. (2020) reported that a residual PPD ≥6 mm following surgical therapy was the strongest risk factor for recurrence of peri-implantitis. Similarly, Serino et al. (2015) found that presence of residual pockets of ≥4 mm at 3 to 4 aspects of an implant following peri-implantitis surgery was a risk factor for progression/recurrence of peri-implant disease. Berglundh et al. (2018) reported that the findings of absence of BoP and shallow PPD after surgical therapy coincided with preserved marginal bone levels during follow-up.

In a follow-up evaluation of surgical treatment of peri-implantitis by Carcuac et al. (2017), implants exhibiting absence of BoP at the clinical examinations at 1 and 3 years had a high probability of presenting with stable marginal bone levels. These results are in line with findings in **Study II**.

Bleeding on probing has in other studies been demonstrated to be of importance in evaluating the risk for future disease progression (Jepsen, Ruhling, Jepsen, Ohlenbusch, & Albers, 1996; Luterbacher, Mayfield, Brägger, & Lang, 2000). The investigations displayed high negative predictive values (probability of stability when the test result is negative) for BoP, suggesting that negative scores may indicate future stable peri-implant conditions.

Clinical parameters are indicative of progression/no progression of periodontal disease at teeth (Lang, Adler, Joss, & Nyman, 1990; Matuliene et al., 2010). In this context it is noteworthy that clinical findings at implant sites are reflective of a history of bone loss as well. It was demonstrated that PPD and BoP were statistically significant indicators of previous bone loss (J. Berglundh, Romandini, Derks, Sanz, & Berglundh, 2021). These data highlight the need for clinical assessments and probing around implants.

One limitation of the present series of studies is the restriction of clinical data, which were assessed at a single time point of examination. At the World Workshop in 2017 (T. Berglundh, Armitage, et al., 2018), it was recommended to have a longitudinal understanding of the disease, with focus on an increase of probing depth between two time points. This implies that clinical evaluations at different time points are required. A further limitation of the present series of studies is the fact that soft tissue recession was not assessed. Information on recessions might have contributed to the understanding of bone loss and pocket depth, as indicated by Romandini et al. (2021), who found a higher prevalence of buccal soft tissue dehiscence at implants diagnosed with peri-implantitis.

Costs associated with implant-supported restorative therapy

In **Study IV**, we used standard amounts for different treatment costs, which may not fully reflect individual situations. Moreover, they may not be directly transferable to international standards. In Sweden, the costs for dental treatment are partly reimbursed by the Swedish Social Insurance Agency (SSIA), which means that individuals do not have to carry the entire cost for the treatment. Disregarding the proportions of cost carried by the patient or other stakeholders, the overall cost and economic burden has to be assessed.

Cost-effectiveness of implant-supported restorative therapy compared to other treatment alternatives

There are only a limited number of studies reporting on cost-effectiveness of implant-supported restorative therapy in comparison to tooth-supported

prostheses, and the ones that are available often rely on short periods of follow-up. Treatment strategies, other than implant-supported restorative therapy, have been evaluated more frequently from an economic perspective (Antonarakis, Prevezanos, Gavric, & Christou, 2014; Cortellini, Stalpers, Mollo, & Tonetti, 2020; S. G. Kim & Solomon, 2011; Pennington et al., 2009).

In the case of having the option of retaining a compromised tooth, some alternatives to implant therapy could be considered. For instance, Schwendicke et al. (2014), investigated the cost-effectiveness of treating molars with furcation involvement compared to replacing them by implant-supported single crowns. It was reported that retaining molars was the more cost-effective choice of therapy. In the present project patients were selected on the basis of having received implant-supported restorative therapy. Thus, comparisons with tooth-supported restorative therapy could not be performed.

Instead, we estimated the cost of preventive measures and treatment procedures associated with the implant-supported restorative therapy. We observed that the cost for preventive measures was similar in different groups of patients. The cost for reparative measures was higher for patients with full-jaw restorations compared to single-crown restorations. The highest costs were observed for patients experiencing implant loss. As the data were restricted to patient files, we could not estimate other costs related to travelling, absence from work, etc. As mentioned, the costs used for the evaluations were based on information from the Dental and Pharmaceutical Benefits Agency (TLV) and were not the precise costs that patients needed to pay, which is a shortcoming in **Study IV**.

Time of follow-up

Schwendicke et al. (2014) observed that re-treatment procedures required for implant-supported crowns were performed significantly later than corresponding treatment procedures on tooth-supported crowns. Thus, the length of the observation period of studies on cost-effectiveness comparing different treatments including implant-supported therapy should be extensive enough

to capture costs associated with the management of long-term complications. One of the strengths in this project is the length of follow-up of about 9 years.

Brägger et al. (2005) concluded that, in patients requiring single-tooth replacement, implant-supported restorative therapy was superior compared to tooth-supported FDPs in terms of cost-effectiveness. A major problem in previous assessments of cost-effectiveness of different treatment procedures is the length of follow-up period. Thus, the 1-4 years observation period by Brägger et al. (2005) was probably too short to capture all complications. Although simulation models were used in the investigation by Bouchard et al. (2009), the data source for implant studies represented, for the majority, a follow-up of <5 years.

Final considerations

Implant-supported restorative therapy in the treatment of patients suffering from partial or full edentulism presents with high success rates and patient satisfaction. However, complications associated with implant treatment are common and they most often require professional interventions. Hence, paying attention to risk factors for complications already in the stages of treatment planning is necessary. By understanding and considering potential risk factors complications may be avoided with obvious benefit for patients and society in general (e.g. costs).

Risk assessment is essential prior to implant therapy, and should include evaluations of site-specific factors, as well as patient-related factors. Caregivers need to include prognosis of chosen therapy, as well as priorities of the patient when deciding on a treatment. Patients who will be provided with implant-supported restorative therapy should, preceding treatment, be informed about potential complications and associated consequences in terms of additional therapy. Maintenance care should be provided, during which clinical evaluations should be performed to evaluate the status of surrounding tissues at implant sites. This enables early detection of peri-implant disease and, adequate treatment measures can be provided to arrest disease progression. In cases of more pronounced and persisting disease, surgical

interventions should be provided to successfully resolve disease and prevent further progression.

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Appendix

I. Karlsson K, Derks J, Håkansson J, Wennström JL, Molin Thorén M, Petzold M, Berglundh T.

Technical complications following implant-supported restorative therapy performed in Sweden.

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II. Karlsson K, Derks J, Håkansson J, Wennström JL, Petzold M, Berglundh T.

Interventions for peri-implantitis and their effects on further bone loss: A retrospective analysis of a registry based cohort.

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III. Karlsson K, Derks J, Wennström JL, Petzold M, Berglundh T.

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IV. Karlsson K, Derks J, Wennström JL, Petzold M, Berglundh T.

Health economic aspects of implant-supported restorative therapy.

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