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Journal of Odontology

Research Article

Efficacy of Air-Polishing Devices without Removal of Implant-Supported Full-Arch Prostheses.

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ABSTRACT

Purpose: The aim of this study was to evaluate cleaning effectiveness of glycine powder air-polishing when applied on implant-supported full-arch restorations without removal of the fixed prosthesis.

Materials and Methods: 85 patients with a total of 357 implants supporting full-arch fixed rehabilitations were included. After removal of the prosthesis (T0) these parameters were recorded: plaque Index (PI), peri-implant spontaneous bleeding (SB), probing depth (PD), bleeding on probing (BOP). The prosthesis was then screwed again. Patients were divided in three groups, each including two hygienic therapies, randomly administered on each hemiarch, according to a split-mouth design. The feasible treatments were: glycine air-polishing (G) and use of sponge floss vs dental sponge floss only (S) in Group 1; G vs ultrasonic device with a PEEK fiber tip-coating (P) in Group 2; G vs carbon fiber curette and use of sponge floss (MS) in Group 3. After instrumentation the prosthesis was removed in order to asses PI and SB. Patients' comfort and satisfaction towards the various treatments was recorded by questionnaires.

Results: G treatment provided a significantly higher reduction of plaque around implants compared to control treatments (S, P, MS) ($p = 0.020$). GS provided the maximum reduction of plaque deposits on the prosthetic surfaces. On average 80 % of patients rated glycine air-flow the top score of satisfaction.

Conclusion: Glycine air-polishing in professional oral hygiene of implant-supported full-arch restorations is highly effective and comfortable. The removal of the prosthesis during professional oral hygiene sessions is recommended for optimizing plaque deposits removal.

Keywords: dental implants, oral hygiene, air-polishing, glycine, full arch.

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Received date: October 13, 2020, 2020; **Accepted date:** August 30, 2021, 2021**; Published date:** September 10, 2021

Citation: Delucchi F (2021) Efficacy of air-polishing devices without removal of implant-supported full-arch prostheses. J Odontol. 5: p719

INTRODUCTION

Nowadays, the use of implant-supported full-arch immediate loading prostheses is widespread for the rehabilitation of patients with severely compromised dentition or total edentulism1,2,3.

Several papers report the outcomes of this kind of rehabilitation, however, the follow-up and maintenance protocols that are fundamental in order to prevent complications or implant failures have not been investigated.

Implant rehabilitation can go through long-term biological complications, usually classified in peri-implant mucositis, defined as “presence of inflammation in peri-implant soft tissue with no appreciable peri-implant bone loss", and peri-implantitis, defined as “presence of an inflammatory process around an implant, including both soft-tissue inflammation and progressive loss of supporting bone beyond biological bone remodeling”4.

The majority of the authors relate plaque accumulation around the implants to the onset of mucositis5,6,7, and the conversion from mucositis to peri-implantitis may be related to the absence of a supportive maintenance of care8, and this seems to also be enhanced by a long function time9.

However, the etiological factors of inflammatory processes of the peri-implant tissue, accompanied by peri-implant bone loss and implant failure are still not clear to this day10. In particular, the specific endogenous characteristics of the host (i.e., individual susceptibility) may have a strong influence on the success of the rehabilitation11.

Although there are several uncertainties in this context, the maintenance of good oral hygiene is recommended in order to provide long-term success rates of titanium dental implants12.

Nevertheless, using traditional manual instruments to clean the contaminated implant surfaces and prostheses with bacterial biofilm may be a challenge for clinicians. Proper hygiene in full-arch prostheses may be hampered by some physical obstacles such as in the case of small and narrow peri-implant pockets or because of the fixed implant-supported prosthesis itself.

Moreover, different combinations of chemical and physical treatments are now available to create micro-textured implant surfaces13. The microscopic irregularities of rougher titanium surfaces may enhance osseointegration, but may also promote microbial adhesion14. Moreover, roughened surfaces combined with the narrow spaces between the implant threads physically prevent traditional manual instruments from reaching and removing the entirety of the biofilm from the implant15.

Some in vitro studies16,17 have demonstrated that metallic instruments may damage the fixture, thus compromising its roughness at a microscopic level and promoting bacterial colonization. Therefore, minimum alteration of the implant surface should be the main objective of any cleaning process15.

According to a recent review18 non-metal instruments and rubber cups should be the first choice for the treatment of smooth surfaces. Non-metal instruments for manual scaling (plastic, carbon-fiber-reinforced composites, teflon or titanium-coated curettes) and air abrasives should also be preferred in cases of rough implant surfaces in order to maintain surface integrity.

Another option is the application of ultrasonic devices provided with a tip-coating made of non-metallic materials (i.e., plastic, Polyether Ether Ketone - PEEK fiber, etc.).

Air-powder polishing has been investigated as an alternative to traditional methods for dental implant decontamination. Air-flow devices provide a high-pressure ejection of water combined with abrasive particles, powered by a stream of water and compressed air19.

These systems are able to work both on a supra-gingival level (on implant abutments and prosthetic surfaces) as well as in the implant grooves20 with testing having reported consistent results21.

Various air-polishing powders are currently available on the market, but conventional sodium bicarbonate air-polishing ($NaHCO_3$) was the first to be employed and investigated and it is the most used. In vitro, it has proven to accurately and effectively remove plaque biofilm and bacterial endotoxins on both implant and abutment surfaces, regardless of the surface’s roughness18. However, according to some authors, its abrasivity may cause modifications to the implant surface such as an increased roughness with crater formation24,25 and deposits of powder particles. In addition, soft tissue abrasion and emphysema may result from sodium bicarbonate air-polishing application21.

More recently, low-abrasive amino acid glycine powder has been introduced resulting in a thorough effect in removing plaque biofilm from both implant and abutment surfaces (in vitro and in vivo)24, while preserving the implant surface and with minimum trauma to soft tissues22.

According to a recent systematic review, glycine powder supra- and sub-gingival air-polishing seemed to ensure the patients’ comfort during non-surgical periodontal therapy25. Similarly, our previous randomized split-mouth study concluded that the use of glycine air-polishing for professional oral hygiene on implants and conical abutments provided high levels of both cleaning efficacy and patient satisfaction26.

According to an in vitro study27, even if glycine air-flow can’t ensure a complete implant surface decontamination, in wide peri-implant defects it allows for most of the surface to be cleaned.

In in vitro or in vivo studies, residue of silicon and carbon were found on the surfaces treated with glycine and sodium bicarbonate respectively, even if glycine air-polish seemed to result in a lower level of surface contamination12,6,28,29. In addition, glycine has proven to actively inhibit bacterial adhesion on implant surfaces after 24 h, as well as seeming to be less aggressive than sodium bicarbonate powder23.

Despite the widespread use of implant-supported full-arch fixed rehabilitation, there is not clear scientific evidence on the protocols to manage professional oral hygiene in these clinical

cases and clinical research comparing different treatment options is scarce.

In a previous clinical trial26, the authors investigated the clinical effectiveness of glycine powder air-polishing against two other types of professional oral hygiene treatments which had been applied after removal of the implant supported full-arch prostheses. Glycine air-polishing showed high levels of both cleaning efficacy and patient acceptance.

In the present study glycine air polishing was applied without removing the implant-supported prostheses. The possibility to perform a professional oral hygiene session without removing the implant-supported fixed prostheses would bring several advantages, including:

Autonomous work for the Dental Hygienist without the need of the Dentist to remove and reinsert the prostheses.

Reduction of chair-side time in favor of the comfort of both the clinician and the patient.

Preservation of the implant prosthetic components from the deterioration following repeated screwing and unscrewing.

The primary aim of the present study was to evaluate the efficacy of different professional oral hygiene systems applied without the removal of the implant-supported full-arch fixed prostheses. Specifically, glycine air-polishing was compared with other therapies.

The second aim of this study was to estimate patient comfort and satisfaction towards the performed hygienic therapies.

MATERIALS AND METHODS

Study design and population

Between February 2015 and May 2018, a consecutive cohort of 85 patients (66 ± 9 years old; range: 45-88 years old; 46 males, 54%) with 357 implants were enrolled in the present study at the Division of Implant and Prosthetic Dentistry, Department of Surgical Sciences (DISC) of Genoa University, Italy.

The patients included had to be treated with an immediate loading full-arch screw retained implant prostheses in the maxilla or mandible, according to the Columbus Bridge Protocol (CBP)1,30. The protocol provides the full-arch rehabilitation of atrophic jaws using a reduced number (4 to 6) of immediate loading implants. The fixed screw-retained prostheses are delivered 24 hours after surgery and are provided with a metal framework and a composite resin veneering material (Fig. 1). The patients received specific hygienic and dietary instructions at the time of the rehabilitation in order to favor peri-implant tissues healing and maintenance31.

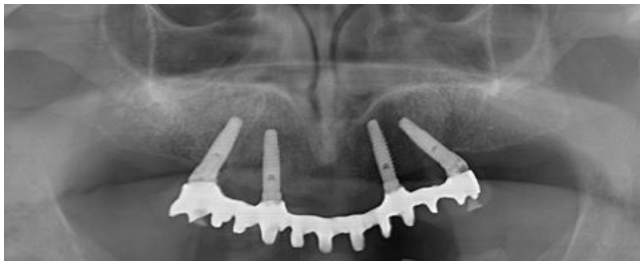


Figure 1: Panoramic radiograph of one of the patients included in the present research (group 1) rehabilitated with a full-arch rehabilitation in the upper jaw according to the Columbus Bridge Protocol (CBP).

When their periodic professional oral hygiene session occurred, patients were recruited for the present research (a split-mouth, one-day study) if they met the following inclusion criteria:

- ≥ 18 years of age.
- good general health, with ASA (American Society of Anesthesiologists) level of risk < 2
- patients who have been rehabilitated with implant-supported full-arch prostheses according to the Columbus Bridge Protocol (CBP) in the maxilla and/or mandible since at least 12 months.
- Exclusion criteria were the following:
- heavy tobacco smokers (≥ 10 cigarettes/day).
- pregnant or in lactation patients.
- patients affected by hepatitis, cardiovascular diseases or systemic autoimmune diseases with or without oral tissue involvement (e.g., systemic lupus erythematosus, lichen ruber planus, HIV).
- biologic complications (e.g., failure of osseointegration process, implant mobility or loss) affecting one or more implants after the delivery of the implant-supported prostheses.
- patients who have received a diagnosis of peri-implantitis considering the criteria proposed by Lindhe et al32 (i.e., probing depth ≥ 5 mm, positive bleeding on probing [BOP] and suppuration, radiographic evidence of marginal bone loss ≥ 2 mm, implant thread exposure ≥ 1 mm) affecting one or more implants.
- patients being treated with medication that may cause gingival tissue growth as a proven side effect (e.g., immunosuppressant, anti-epileptic and calcium channel antagonist drugs), as well as cortisone or antibiotic therapies within the previous 3 months or during the study period.

The study was performed in full agreement with the World Medical Association Declaration of Helsinki (as revised in 2008) and received the approval of the local ethical committee.

The study protocol was widely and clearly explained to all the patients and all of them signed an informed consent form to participate in the research.

Baseline Assessment (T0)

The screw-retained full-arch prosthesis was removed from the maxilla and/or mandible, in order to record the following peri-implant parameters (T0): spontaneous bleeding (SB), Plaque Index (PI), probing depth (PD), bleeding on probing (BOP) and peri-implant tissue-suppuration (PS).

SB was evaluated at four sites on each implant.

PI was assessed at four sites (mesial, distal, lingual, buccal) with the use of a disclosing solution (Butler GUM Red-Cote liquid, Sunstar Americas), and values from 0 to 4 were recorded for each implant/conical abutment. PI was also assessed at the level of the fixed prosthesis, recording the Plaque Index on the mucosal surface of each prosthetic tooth (values from 0 to 4 for each tooth).

The recording of PD (considered as the distance in mm between the peri-implant mucosal margin and the most apical portion of the peri-implant sulcus) was taken with a plastic probe (12 Color Vue Probe, Hu-Friedy), using a force of about 0.2 N. It was evaluated at 4 sites (mesial, distal, lingual, buccal) on each implant/abutment and the measurements were rounded to the nearest millimeter.

BOP was assessed at 4 sites (mesial, distal, lingual, buccal) and values from 0 to 4 were recorded for each implant/abutment.

PS was simply recorded with a dichotomic evaluation (present/absent).

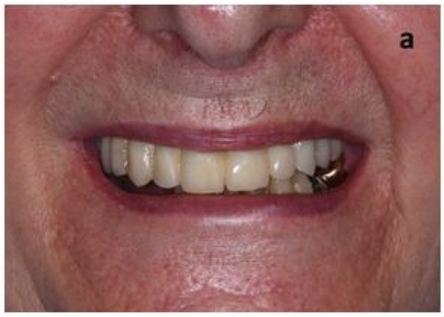
The possible presence of loosened implant abutment screws was also recorded at this time.

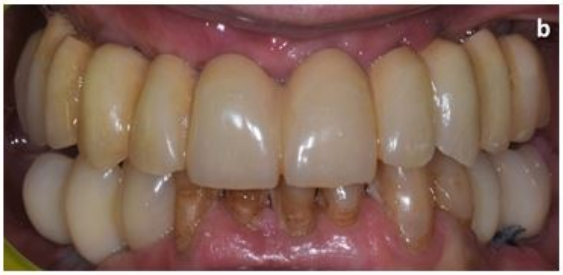
Finally, the position (maxillary or mandibular) and the type of prostheses (i.e., "Natural Bridge" prostheses including only teeth, or "Toronto Bridge" prostheses with a resin reproduction of the soft tissues) were also recorded.

Intervention

After baseline recordings, the prosthesis was repositioned, in order to start the professional hygiene treatment (Fig. 2 a, b).

Figure 2: Extra-oral (a) and intra-oral (b) frontal views of the same patient in Figure 1 before hygienic treatment.





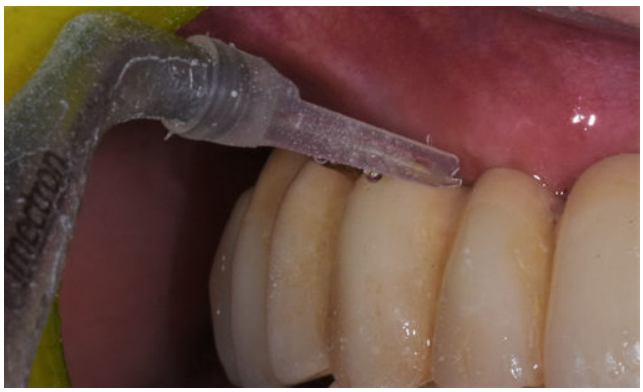
All the patients received two different professional oral hygiene treatments with the treatments administered following a split-mouth method: each hemiarch (each including two or three implants) randomly received one of the two possible treatments. The randomization process was performed with a 1:1 allocation ratio using a random number table.

The patients were randomly divided in 3 groups based on the hygienic treatments that were performed.

Group 1 received the following treatments

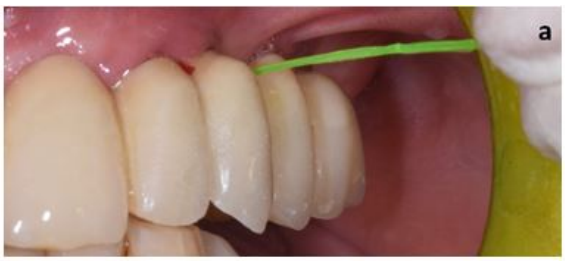
Treatment GS: glycine powder air-polishing (Glycine powder, Mectron SpA, Carasco, Italy; particle size < 63 μm) for 20 seconds (10 seconds on the buccal side and 10 seconds on the lingual side); subsequent application of a dental sponge floss (x-Floss iDontix, ROEN s.a.s. di Boarolo Paolo e Marco & C., Via Torino 23, 10044 Pianezza TO - Italy), for 5 sec per prosthetic span (the space between two consecutive pillars) (Fig 3; Fig 4 a, b).

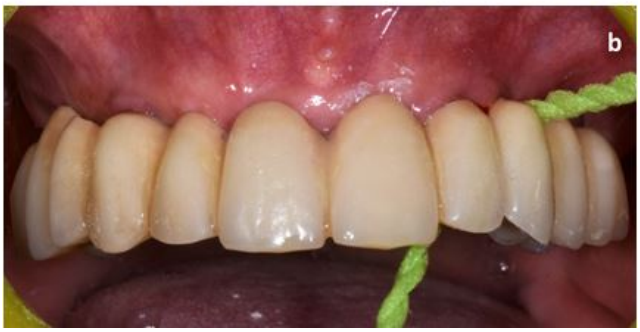
Figure 3: Application of glycine air-polishing.



Treatment S: application of a dental sponge floss (x-Floss iDontix), for 20 sec per prosthetic span.

Figure 4: a, b Plaque removal through the use of the dental sponge x-Floss.





Group 2 received the following treatments

Treatment G: glycine powder air-polishing for 20 sec (10 sec on the buccal side and for 10 sec on the lingual side).

Treatment P: application of an ultrasonic device, provided with a tip-coating made of Polyether Ether Ketone (PEEK) fiber (Implant Cleaning Set, Mectron) for 20 sec (10 sec on the buccal side and 10 sec on the lingual side).

Group 3 received the following treatments

Treatment G: see details above.

Treatment MS: manual scaling with carbon-fiber curettes (Implant Deplaquer Hawe Neos, Kerr Italia srl. Via Passanti 332, 84018 Scafati Italia) for 20 sec, followed by the application of a dental sponge floss (x-Floss iDontix); subsequent application of the same dental sponge floss as treatments GS and S, for 5 sec per prosthetic span.

All the professional oral hygiene treatments were performed by an experienced dental hygienist.

The glycine powder was delivered making circular movements with the air-polishing unit Combi Touch (Mectron). The spray nozzle used had an angulation of 120 degrees, it was placed about 5 mm from the implant and the "perio" feature was set (mean ejection pressure of 2, 7 bar).

The hand-piece was placed in order to make the powder jet have an angle of incidence between 30 and 60 degrees with the dental axis, the aim being to avoid soft tissue trauma and reducing the aerosol emission33,34.

G treatment time (20 sec) was arbitrarily chosen on the base of data reported in other similar studies35 and the same treatment time was established for the remaining treatments in order to standardize the procedures.

Post-intervention assessment (T1)

SB and PI were assessed again after oral hygiene treatment (T1) following the same methods described above for T0 (Fig 5 c, d). PI was recorded again both at the implant/abutment level and on the prostheses. The clinician who collected the data was not informed regarding the hygienic treatment applied.

At the end of T1 clinical assessment the fixed prosthesis was redelivered to the patient.

Next, all the patients were left alone (in order to avoid bias) and asked to complete an anonymous 45-items questionnaire about their satisfaction with respect to the oral hygienic procedures. They were also allowed to further elaborate on their experience in an area provided for written comments. The questionnaires were specifically created for this study and a clinician intervened during compilation only if specifically requested by the patient.

In particular, patients responded to the following points:

- If they had had previous knowledge of the oral hygienic treatments applied in this study (yes/no).
- How comfortable they had felt with the two different oral hygienic treatments (one for each hemiarch). The comfort was described using a scale of 0-5, where 0 meant the maximum discomfort and 5 the maximum comfort.
- Which of the two treatments they felt had been the most comfortable (GS/F/no difference; G/P/no difference; G/MS/no difference).
- If they had found the possibility of having the professional oral hygiene treatment without the removal of their fixed prostheses positive.

Statistical analysis

The mean with standard deviation or median with interquartile range (IQR; 25th-75th percentile) were reported for quantitative characteristics. In this regression model the dependent variable was the outcome and the independent variables were the time indexes, the treatment group (i.e., type of hygienic technique) and their interaction.

Longitudinal assessment for the results was considered as difference of measurements at different time-points: T0 and T1.

The variable PI1_0 was calculated, that is the "delta" (difference) between Plaque Index at T0 (PI0) and Plaque Index at T1 (PI1), resulting therefore in a negative value when PI1 < PI0.

In order to evaluate the efficacy of glycine air-polishing (G), which was considered the test treatment, its clinical performance was compared to that of the other treatments (GS, S, P, MS) which were considered control treatments.

$P < 0.05$ was considered statistically significant and SPSS Statistics (Statistical Package for Social Science, v.21, IBM) was used for the computation.

RESULTS

Baseline characteristics of the population

A total of 85 patients, 85 CBP prostheses and 357 implants, were selected according to the inclusion and exclusion criteria and were those who had accepted to participate in the present study. Four additional patients meeting inclusion and exclusion criteria did not accept to participate in the study as they were not willing to remove the fixed prostheses.

The mean follow-up since implant rehabilitation for the patients included was 4.67 years (range: 1-13 years). All the characteristics of the sample are summarized in Table 1.

Table 1: Characteristics of the patients enrolled in the present research.

Characteristics		Patients(n= 85)
Gender	Male	46 (54%)
	Female	39 (46%)
Age (years)	Mean ± SD	66 ± 9
	Range	45-88
Treated arch	Maxilla	61 (72%)
	Mandible	24 (28%)

Prosthesis	Toronto bridge	21 (25%)
	Natural Bridge	64 (75%)
Number of implants for each prosthesis	5 or 6	13 (15%)
	4	72 (85%)
Time of implant rehabilitation (years)	Mean ± SD	4.67 (3.08)
	Range	13-Jan

The patients were divided into three groups. Patients in group 1 (n = 29) were treated with two different control hygienic therapies (S or GS) for each hemiarch. Patients in group 2 (n = 40) were treated with the test hygienic therapy G in one side of the arch, and with the control therapy P in the other side. Patients in group 3 (n = 16) were treated with the test hygienic therapy G in one side of the arch and with the control therapy MS in the other side.

Among the 357 total implants, 119 received the treatment G (33%), 238 received the control treatments (67%). The control group was divided as follows: 63 implants were included in group S (27%), 83 in group P (35%), 32 in group MS (13%), 60 in group GS (25%).

Table 2: Descriptives regarding the hygienic treatments

	Treatment	Age	Gender (male) per implant	Prosthesis (Toronto)	Treated arch (lower)	Exposed abutment (no)
Control	S* 27%	67	49%	21%	30%	92%
	P* 35%	66	69%	23%	28%	86%
	MS* 13%	66	25%	38%	25%	84%
	GS* 25%	67	47%	20%	30%	90%
Control 67% (238/357)		66	52%	24%	29%	88%
Test 33% (119/357)	G*	66	60%	28%	29%	87%
Controls + Test n = 357		66	54%	25%	29%	88%

An investigation into the baseline characteristics was conducted between G and control groups of implants (Table 2). T-student was conducted for age, Chi square test for gender, type of prosthesis, treated arch, and abutment type (p = 0.796).

The sample groups did not show any significant difference at baseline regarding demographic characteristics.

The only significant difference was detected for the variable gender between treatment G vs treatment MS.

Clinical evaluation

T-student test was used to investigate the statistical difference between test treatment (G) and the set of controls (F, P, M, GS) for PI1 (p = 0.191), PI2 (p = 0.086), PI_10 (p = 0.020), BOP1 (p = 0.807), SB1 (p = 0.783), SB2 (p = 0.094), PD at T0 (p = 0.014). G treatment provided a significantly greater reduction of Plaque Index around implants (-2.17 ± 1.50) if compared with the controls (-1.78 ± 1.42).

Table 3: Descriptives regarding the clinical evaluation reported as mean (standard deviation).

When Levene (variance) test detected a different pattern distribution, the corrected T student test value has been reported.

	Treatment	PI at T0	PI at T1	PI 1-_0	BOP at T0	SB at T0	SB at T1	PD at T0	PS at T0	PS at T1
Control	S (n = 63)	2.73 (1.26)	1.32 (1.16)	-1.41 (1.16)	0.46 (0.84)	0 (0)	0.19 (0.52)	1.51 (0.52)	0 (0)	0 (0)
	P (n = 81)	2.70 (1.3)	0.95 (1.13)	-1.75 (1.58)	0.52 (1.10)	0 (0)	0.33 (0.95)	1.80 (0.59)	0 (0)	0 (0)
	MS (n = 32)	2.84 (1.35)	0.44 (0.80)	-2.41 (1.39)	0.22 (0.42)	0.06 (0.25)	0.22 (0.49)	6.03 (2.19)	0 (0)	0 (0)
	GS (n = 60)	2.65 (1.34)	0.78 (0.80)	-1.87 (1.35)	0.18 (0.47)	0.02 (0.13)	0.10 (0.35)	1.43 (0.52)	0 (0)	0 (0)
Control n = 236		2.72 (1.30)	0.94 (1.06)	-1.78 (1.42)	0.38 (0.81)	0.01 (0.11)	0.22 (0.67)	2.20 (1.80)	0 (0)	0 (0)
Test	G n = 117	2.91 (1.25)	0.74 (1.00)	-2.17 (1.50)	0.40 (1.03)	0.02 (0.19)	0.36 (0.84)	2.76 (2.04)	0 (0)	0 (0)
Test + Control n = 353		2.78 (1.28)	0.87 (1.04)	-1.91 (1.45)	0.39 (0.89)	0.01 (0.14)	0.27 (0.73)	2.39 (1.90)	0 (0)	0 (0)

T-student test was also used to investigate the statistical difference on single control treatments versus the test G therapy (Table 3).

PI at T0 for all patients presented a mean of 2.78 ± 1.28 (69.5%) surfaces involved.

Despite the presence of abundant plaque deposits before the hygienic treatment, baseline mean PD (2.39 ± 1.90 mm) and BOP (0.39 ± 0.89) showed physiological values.

A putative correlation between prostheses type and clinical parameters was investigated using Person's correlation coefficient and a significant difference was found between Toronto and Natural bridges for PI and PD at T0 (Table 4). In fact, PI and PD were significantly greater in Toronto compared to Natural bridges at T0.

Table 4: Correlation between prostheses type and clinical parameters recorded at implant/abutment level

		PI0	PI1	BOP1	SB1	SB2	PD
Prostheses	Toronto	3.01 (1.29)	1.04 (1.29)	0.34 (0.78)	0.00 (0.00)	0.25 (0.71)	2.89 (2.59)
	Natural	2.70 (1.28)	0.81 (0.94)	0.40 (0.92)	0.02 (0.16)	0.27 (0.74)	2.22 (1.58)
	p value	.048	.066	.555	.271	.777	.005

Significant level $p < 0.005$.

After hygienic therapy, the global mean PI value was 0.87 ± 1.04.

MS provided a greater removal of plaque around implants than G, but the difference was not statistically significant.

Mean SB before treatment was negligible, with a mean value equal to 0.01 ± 0.14), and there was no statistical difference between control treatments S, P, MS and test treatment G. SB mean value at T1 was 0.27 ± 0.73. At T1 a statistically significant difference of SB was observed ($p = 0.004$) between GS (0.10 ± 0.35) and G (0.36 ± 0.84).

There were no signs of suppuration for any of the implants involved in the study, neither before nor after hygienic treatment.

Plaque removal at the prostheses' intaglio surface

Eighty-five CBP prostheses were recruited, each including a mean of 10.2 dental elements. Thus, PI was evaluated before and after treatment on a total of 867 prosthetic dental elements. (Fig. 5 a, b, c, d)

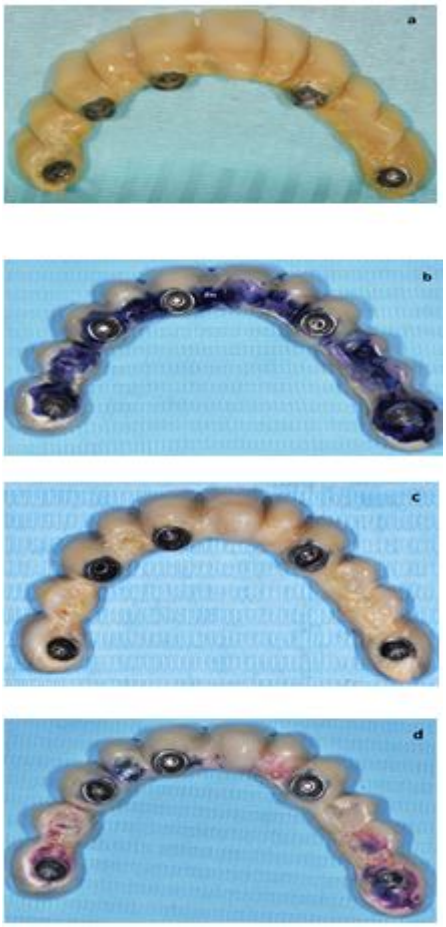


Figure 5: Extra-oral view of the mucosal surfaces of the upper jaw prosthesis of another patients included in the research: immediately after removal (T0) (a), after the first application of the plaque detector (T0) (b), after the hygienic treatment G (c) and after the application of the plaque detector (T1) (d).

The prosthetic hygiene outcomes are summarized in Table 5.

T-student test was used to investigate the statistical difference in prostheses hygiene outcomes between test treatment (G) and the set of controls (S, P, MS, GS). A significant difference was found for PI at T1 and PI_10: controls had both a greater initial level of plaque accumulation (3.50 ± 0.93) and a significantly greater reduction of plaque after treatment (-1.94 ± 1.28; $p < 0.001$). The use of glycine air-polishing only provided the removal of 45.3% of plaque deposits, in comparison to the set of controls (59.3%). However, the most effective treatment was GS, which was able to remove 75.6% of plaque deposits from the intaglio surface of the prostheses.

Table 5: Descriptive regarding the outcomes of hygiene session at the prostheses level.

	Treatment	Age	Gender (male) per implant	Prostheses (Toronto)	Dental arch (lower)	PI at T0	PI at T1	PI_10
Control	S 27% (164/600)	67 (8)	49% (81/164)	22% (36/164)	32% (53/164)	3.71 (0.79)	1.45 (1.25)	-2.25 (1.28)

	P 27% (162/600)	63 (9)	67% (108/162)	30% (48/162)	37% (60/162)	3.28 (1.05)	2.20 (1.19)	-1.07 (1.10)
	MS 18% (108/600)	66 (7)	22% (24/108)	50% (54/108)	22% (24/108)	3.14 (1.00)	1.19 (0.81)	-1.94 (0.96)
	GS 28% (166/600)	67 (8)	49% (81/166)	22% (37/166)	32% (53/166)	3.75 (0.76)	1.29 (1.14)	-2.46 (1.21)
Control 69% (600/867)		66 (8)	49% (294/600)	29% (175/600)	32% (190/600)	3.50 (0.93)	1.56 (1.20)	-1.94 (1.28)
Test	G 31% (267/867)	65 (8)	49% (131/267)	38% (101/267)	31% (83/267)	3.27 (0.97)	1.79 (1.04)	-1.48 (1.11)
Test + Control n = 867		65 (8)	51% (425/867)	32% (276/876)	32% (273/867)	3.34 (0.95)	1.63 (1.16)	-1.80 (1.25)

Mann-Whitney for PI at T1 showed a significant difference between groups ($p = 0.001$) and Mann-Whitney test for PI_10 ($p < 0.001$).

T-student test was also used to investigate the statistical difference in single controls versus the test hygienic therapy:

G vs. S: PI at T0 was significantly lower for G (3.27 ± 0.97), PI at T1 was significantly lower for S (1.45 ± 1.25), PI reduction was significantly greater for S (-2.25 ± 1.28).

G vs. P: PI at T1 was significantly lower for G (1.79 ± 1.04; $p < 0.001$), PI reduction was significantly greater for G (-1.48 ± 1.11; $p < 0.001$).

G vs. MS: PI at T1 was significantly lower for MS (1.19 ± 0.81; $p < 0.001$), PI reduction was significantly greater for MS (-1.94 ± 0.96; $p < 0.001$).

G vs. GS: PI at T0 was significantly higher for GS (3.75 ± 0.76; $p < 0.001$), PI at P1 was significantly lower for GS (1.29 ± 1.14; $p < 0.001$), PI reduction was significantly greater for GS (-2.46 ± 1.21; $p < 0.0019$: 75.6% of initial plaque was removed applying GS versus 45.6% using G.

Comfort evaluation

All patients included in the research filled out the anonymous questionnaire about the degree of satisfaction towards the administered hygienic treatments.

Comfort evaluation was developed by dividing patients into three groups, as previously described.

The outcomes are displayed in Table 6.

Table 6: Descriptives per study group regarding the degree of comfort

Group	N of patients for group	Comfort GS	Comfort S	Comfort G	Comfort P	Comfort MS	Preference	Prostheses removal helpfulness
Group 1*	29	"2" 3% (1) "4" 7% (2) "5" 90% (26)	"1" 3% (1) "2" 3% (1) "3" 3% (1) "4" 28% (8) "5" 63% (18)	-	-	-	GS 24% (7) S 7% (2) Indifferent 69% (20)	Very helpful 3% (9) Quite helpful 14% (4) Not very helpful 41% (12) Not helpful at all 14% (4)
Group 2*	40	-	-	"3" 2% (1) "4" 23% (9) "5" 75% (30)	"1" 13% (5) "2" 2% (1) "3" 27% (11) "4" 25% (10) "5" 33% (13)	-	G 70% (28) P 25% (10) Indifferent 5% (2)	Very helpful 33% (13) Quite helpful 33% (13) Not very helpful 33% (13) Not helpful at all 1% (1)
Group 3*	16	-	-	"4" 25% (4)	-	"2" 6% (1)	G 75% (12)	Very helpful 31%

	"5" 75% (12)	"4" 6% (1) "5" 88% (14)	MS 0% (0) Indifferent 25% (4)	(5) Quite helpful 19% (3) Not very helpful 44% (7) Not helpful at all 6% (1)

*Group 1 = patients treated with glycine air-polishing and dental sponge floss (GS) and sponge floss only (S)

*Group 2 = patients treated with glycine air-polishing (G) and ultrasounds with a PEEK fiber tip-coating (P)

*Group 3 = patients treated with glycine air-polishing (G) and carbon fiber curette with sponge floss (MS).

*Degree of comfort: 1= "not comfortable at all"; 2 = "not very comfortable"; 3 = "quite comfortable"; 4 = "comfortable"; 5 = "very comfortable".

In all three of the groups, glycine air-polishing received the top score of satisfaction from the majority of patients: 90%, 75% and 75%, for group 1, 2 and 3 respectively. No patients in group 3 (G vs MS) rated glycine air-polish lower than a "4".

Also the alternative hygiene treatments had positive feedback and provided a high degree of comfort: in group 1, 63% of the patients rated the dental sponge floss (S) a "5"; in group 2, 58% of patients rated the ultrasound device (P) a "4" or "5"; in group 3, 88% of patients rated the curette manual treatment (MS) a "5".

To the question "Which of the two hygienic therapies applied did you prefer?":

In group 1, the majority of patients (69%) answered there was no difference between the two treatments, 24% preferred G and 7% preferred S.

In group 2 the majority of patients (70%) ranked a preference to G, 25% preferred P and 5% (2) had no preference.

In group 3 the majority of the patients (75%) expressed a preference for G, 25% had no preference and nobody declared a preference for MS.

A new variable called "global preference", merging the results of the three groups was calculated. As a result, 55% of the patients ranked a preference to G compared to all the other therapies (14%), while 31% did not find any difference between G and the alternative therapies.

To the question "Do you consider it helpful not having to remove the prostheses to undergo hygienic treatment?", 55.3% of the patients answered "very" or "quite" helpful; 37.6% answered "not very useful"; 7.1% answered "not helpful at all" since they believed that the removal of the prostheses would improve the cleaning performance.

DISCUSSION

The present split-mouth study investigated the cleaning effectiveness and the comfort felt by patients using glycine powder air-polishing compared to other professional oral hygiene treatments without the removal of the full-arch fixed prostheses from the oral cavity.

For each hygienic procedure the following parameters were evaluated: the ability to remove plaque deposits not only around conical abutments and implants, but also from the mucosal surfaces of implant-supported fixed prostheses, as well as the invasiveness on soft tissues and the degree of patient comfort.

The original main aspect of the present research is that the fixed prostheses were removed before and after treatment in order to record periodontal parameters, while the prostheses were maintained in place during hygiene treatments in order to evaluate the capacity of professional oral hygiene treatments to properly debride implants and prostheses without removing implant-supported prostheses.

The realization of this research protocol was enabled by the design of the Columbus Bridge, which is screw-retained and not cemented on the implant abutments.

According to baseline assessments, the amount of plaque deposits (tables 3 and 4) was high. In fact, home oral hygiene is not easy for patients wearing full-arch fixed prostheses supported by dental implants. This parameter was most likely made worse by the relatively old average age of the study population, with almost half of the patients (49.4%) being ≥ 65 years old and 36.5% being ≥ 70.

Maintaining proper oral hygiene of implant prostheses could be challenging especially in case of Toronto Bridge prostheses where a significantly greater PI and PD were found compared to Natural Bridge prostheses at T0. This highlights that prostheses design strongly affects home oral hygiene, although in the present study professional oral hygiene effectiveness was not significantly affected.

In addition, all the prostheses included in the present research were provided with composite resin veneer. This material could lead to higher plaque accumulation, compared to other materials employed for implant-supported full-arch immediate loading prostheses (such as zirconia, metal-ceramic, etc.)29.

Despite high levels of plaque accumulation in the patients included in the present study, the parameters of peri-implant soft tissues inflammation, PD (mean 2.39 ± 1.90 mm), and BOP (mean 0.39 ± 0.89), were within normal limits at T0.

The use of manual curettes combined with the use of sponge floss demonstrated the greatest efficacy in plaque deposit removal from implants/abutments (84.8%), but without a

statistically significant difference when compared to other treatments.

Air-polishing with glycine-powder was the second most effective method for efficacy in removing biofilm around abutments/implants (74.5%).

Glycine powder air-flow combined with the sponge floss (GS) provided the highest level of plaque removal from the prosthetic surfaces, followed by sponge dental floss used alone (S).

The higher cleaning effectiveness of MS treatment when compared with glycine air-polishing is probably due to the sponge floss that was used in conjunction with the carbon-fiber curette. However, the use of manual curettes only was not evaluated in the present research.

The global evaluation of the results seems to highlight the significant usefulness of sponge dental floss in removing plaque deposits in full-arch fixed prostheses supported by dental implants when applied following manual instrumentation or glycine air polishing especially with respect to the cleaning effectiveness at the level of the intaglio surfaces of the prostheses.

Moreover, glycine powder proved to effectively reduce the presence of plaque from both Natural- and Toronto Bridge prostheses.

It must be underlined that, in contrast to other treatments whose effect is more localized, the effect of glycine air-polishing might have provided a cross over effect to the other side in the midline, especially at the level of the contralateral central incisor. However, we considered this effect negligible. In fact, the spray nozzle was placed very close to the tooth to be treated (5 mm) and directed towards the surface to be treated.

An in vitro study30 showed that glycine air-polishing was able to decontaminate the most part of the bone defects around implants affected by peri-implantitis.

Cochis et al25 confirmed that glycine air-polishing is the most effective and indicated mean to remove plaque from implant surfaces and its bacteriostatic properties are able to fight biofilm formation.

However, none of the professional hygienic treatments performed in the present study were able to completely remove plaque deposits from the implants nor from the prosthetic components.

As a consequence, according to the authors, removal of the prostheses is recommended in order to ensure optimal cleansing, despite the discomfort that it might cause. The frequency of the removal of the prostheses should be determined based on the patients' ability to maintain good home oral hygiene. It must be underlined that prostheses removal is easily done when dealing with screw-retained implant-supported prostheses, but this is not feasible when cemented prostheses are present. The possibility of optimal professional oral hygiene thanks to prostheses removal is one of the advantages of using screw retention in implant prosthodontics. However, wear of the prosthodontic components (screws) should be carefully evaluated as indications on the frequency of their substitution is missing in the literature.

Moreover, it must be underlined that none of the instrumentation techniques evaluated are able to remove hard deposits (tartar), as their efficacy is limited to plaque deposits and some authors34 support the need of mechanical instrumentation in order to remove hard deposits. The choice of the proper instrumentation technique (or combination of different instruments) should balance cleaning effectiveness and low aggressivity on soft tissue, as well as implant and prosthodontic components.

Regarding the aggressiveness of the tested hygienic treatments, SB was assessed. The mean value of SB was low after all the treatments (global mean SB at T1: 0.27 ± 0.73). The greatest SB values (0.36 ± 0.84) were found for treatment G. GS showed a statistically significantly lower SB at T1 compared to other treatments and especially compared to treatment G. This can be explained by the use of the sponge floss, that may have removed some blood residues after glycine air-polishing.

This minimal aggressiveness can be related to various factors, such as brevity of procedures and low invasiveness of the instruments tested compared to traditional metal instruments. It is important to specify that both formulation of powder particles, as well as the pressure of water and compressed air in air-polishing devices have an influence on biofilm removal and on eventual injuries to the soft tissues. The level of abrasivity is directly proportional to the size, granulometry, hardness and sharpness of the particles. The water is also crucial because its stream improves the cleansing action of the powder, as well as dampening its impact on the surfaces.

Satisfying outcomes using glycine may be related to its smaller particle size (about 63 μm or less) in comparison to sodium bicarbonate powders (up to 250 μm)35. In fact, glycine is the smallest extant nonessential amino acid in proteins.

Nevertheless, it is important to follow the instructions for use provided by the manufacturer in order to ensure maximum effectiveness of air-polish treatment and minimum discomfort and complications for the patients.

The low level of glycine air-flow invasiveness was also reflected in the results of the questionnaires of comfort completed by the patients in this research. Most of them showed a clear preference for G treatment, but high scores of comfort were also reported for the other treatments.

The majority of the patients appreciated the possibility to perform dental hygiene sessions without removing the prostheses and 8 patients refused to participate in the present research because they did not want to remove the prostheses. Performing professional oral hygiene without removing implant-supported fixed prostheses would bring several advantages (reduced treatment time, greatest comfort for the patient, independence of the Dental Hygienist, reduced wear of implant prosthodontic components). This encourages further research in order to develop specific protocols for professional oral hygiene in patients rehabilitated with implant-supported full-arch fixed prostheses.

In conclusion, we can stet that good hygienic maintenance in implant-supported restorations is essential to minimize the risk of peri-implant disease. However, the hygienic management of full-arch fixed prostheses is still to be defined with specific protocols.

Professional oral hygiene based on glycine air-polishing can be an effective alternative to manual and mechanical instrumentation (short treatment time and more comfort for the patient) in implant prosthodontics. The additional use of sponge floss after instrumentation seems effective in improving plaque removal at the prostheses level. However, removal of the fixed prostheses is needed to optimize plaque deposit removal.

Further studies should investigate the best treatment options for professional oral hygiene in implant-supported full-arch fixed prostheses and how often full-arch prostheses should be removed to perform professional hygiene sessions.

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