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ORIGINAL ARTICLE

Changes in mastication after an immediate loading implantation with complete fixed rehabilitation

J. L. Veyrune · S. Opé · E. Nicolas · A. Woda · M. Hennequin

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Abstract
Objective This study aimed to measure modifications of mastication after immediate loading full-arch prosthesis (ILFAP) rehabilitation.
Materials and method Fourteen patients were observed before and 6 months after ILFAP rehabilitation when masticating two natural, standardized foods (peanut and carrot) and three model foods with increasing hardness. The granulometry of the expectorated boluses from carrot and peanuts was characterized by median particle size (D50), determined at the natural point of swallowing. Chewing time (CT), number of chewing cycles (CC), and chewing frequency (CF) were video recorded. A self-assessment questionnaire for oral health-related quality of life [Geriatric Oral Health Assessment Index (GOHAI)] was also used.
Results After ILFAP rehabilitation, the mean D50 values for carrot and peanuts were smaller [Repeated Model Procedures (RMP), F=41, p<0.001]. Mean CT and CC values recorded with the three model foods decreased, while CF increased regardless of the model food hardness (RMP, F=14, F=10, and F=11, respectively, p<0.001). The GOHAI score increased from 43±9 to 56±3 (t test, p<0.001).
Conclusion ILFAP rehabilitation improves the ability to reduce the bolus particle size and the ability to discriminate between different food hardnesses in the 6 months post-surgery period.
Clinical relevance This study encourages the clinical development of immediate loading implantation with a fixed full-arch prosthesis protocol.

Keywords Oral rehabilitation · Implants · Immediate loading · Mastication

J. L. Veyrune · S. Opé · E. Nicolas · A. Woda · M. Hennequin
Clermont University, University of Auvergne,
CROC-EA 4847 Clermont-Ferrand, France

J. L. Veyrune · S. Opé · E. Nicolas · M. Hennequin
CHU of Clermont-Ferrand,
Clermont-Ferrand, France

M. Hennequin (✉)
Faculté de Chirurgie Dentaire,
11, Bd Charles de Gaulle,
63000 Clermont-Ferrand, France
e-mail: martine.hennequin@u-clermont1.fr

Introduction

The current trend for dental implant procedures seeks to reduce the oral processing time, often considered too long by patients, particularly for those requiring one or two full-arch rehabilitations. Consequently, immediate loading of dental implants has been recommended as a new procedure [1–3]. Several experiments have confirmed that the implant survival rates are similar after delayed or immediate loading [4–6]. This success rate appears to be similar when rehabilitation with a fixed full-arch prosthesis is added to the immediate loading procedure [7].

The main functional goal of full-arch implant-supported dentures is to improve mastication, and this is addressed by the conventional delayed loading procedure [8–10]. The impact on the masticatory function of the new approach, combining immediate loading with fixed full-arch prosthesis (ILFAP) rehabilitation, has not been investigated. Whether mastication could be impaired after ILFAP rehabilitation is an important question since this protocol implies serious risk of proprioception impairment. Several factors suggest that nervous control of mastication is deeply disturbed. Firstly, in the ILFAP procedure, loading of the dental implant succeeds extractions immediately. This induces a sudden suppression of proprioceptive inputs from the periodontal mechanoreceptors. Secondly, the immediate loading protocol gives no time to accustom the mastication center to the new intercuspal occlusion via the muscle proprioceptors, and the spindle and Golgi receptors [11]. In addition, after the ILFAP procedure, the deficit in proprioception cannot be compensated for by mucosa support. Finally, mastication functions a couple of days after the ILFAP procedure, and there is no time for reinnervation. After a conventional implantation procedure, nerve regeneration [12] and associated osseoperception occur [13, 14]. This nerve regeneration probably explains the sensory recovery and the consequent motor feedback [10, 15] which permits the partial recovery observed for kinetic chewing parameters and masticatory function [4, 16]. Little is known about the reinnervation process after immediate loading procedures [17].

An impaired proprioception may directly impact the neural control of the oral motor functions, leaving ILFAP patients with a deficient mastication. The observation of the food bolus collected just before swallowing associated with the kinematic parameters developed to produce this bolus appeared to provide a good criterion for distinguishing patients with normal mastication from those with seriously impaired mastication [18, 19]. Impaired mastication leads to an increase in food bolus particle size, which is better evaluated by the median of the particle size distribution of the food bolus at swallowing (D50). Using raw carrot as test food, a cutoff value of 4 mm called the masticatory normative indicator (MNI) has recently been shown to differentiate subjects with impaired mastication from those with a normal function [19]. In healthy, fully dentate subjects, the D50 value is below 4 mm for carrot.

The adaptation of chewing behavior to food hardness can also characterize a healthy mastication. That has been shown during mastication of edible viscoelastic model foods. An adaptation to increasing food hardness results in an increase in both the number of chewing cycles and the duration of the masticatory sequence. This adaptation occurs with no modification of the chewing frequency (number of cycles/second within the mastication sequence) [20–22]. Moreover, mean chewing frequency within the masticatory sequence is retarded while eating any type of resistant food in groups of subjects with impaired mastication. This has been observed in many groups with deficient mastication. Dentate and edentate elderly persons eating hard foods and persons with Down syndrome are recognized examples of persons who exhibit chewing frequency variability [23–26].

This study was designed to verify the rehabilitation of the adaptation process during mastication. The following three hypotheses were tested: (1) After ILFAP rehabilitation, patients should be able to improve the granulometry of the preswallowed bolus of carrot and peanuts. This should be demonstrable by a decrease in D50 values after ILFAP rehabilitation. More particularly, the D50 value for carrot should be in the range of MNI normality, i.e., 4 mm; (2) After ILFAP rehabilitation, patients should be able to adapt their chewing behavior to the food hardness with an increase in chewing cycle (CC) and chewing time (CT) in response to a food hardness increase, while no change in chewing frequency (CF) occurs; (3) After ILFAP rehabilitation, the chewing frequency could be increased. Finally, the impact of ILFAP rehabilitation on food refusals and oral health-related quality of life will also be explored.

Material and methods

Study design

The study was prospective and observational, and the subjects functioned as their own controls. Recruitment extended over 12 months in the Dental Department of the University Hospital of Clermont-Ferrand, France. The study was approved by the local ethics committee (CECIC, 2010/06; IRB number, 5044), and all the subjects provided written informed consent. Each subject attended two sessions for mastication evaluation. The first session was organized during the month preceding the ILFAP intervention and the second during the sixth month after the intervention.

Subjects

The required sample size was estimated from a previous study [27] that measured the carrot bolus granulometry in a group of full denture wearers whose dentures were replaced. The mean D50 values of the carrot bolus decreased from 3,905±2,502 μm (while the patients wore the old denture) to 2,642±1,401 μm (when wearing the new denture). Calculations were based on this difference (1,263±2,142 μm) for a continuous criterion with paired values and indicated the need for 14 subjects (α=5 %, β=10 %).

Patients attending a preoperative consultation for one full-arch implant procedure were examined by a dentist. Patients for whom the antagonist arch was either healthy or rehabilitated with fixed or removable full denture that satisfied the academic criteria for good quality were proposed for inclusion.

Surgical procedure

Fourteen patients (ten women, 62.9±6.3 years old; four men, 65±4.0 years old) were scheduled for a full-arch clearance and subsequent rehabilitation with four to eight implants per arch immediate loading. The surgical phase was conducted in three steps, aiming to respect the natural occlusal relationships. Firstly, two or three posterior teeth in articulation with antagonists teeth were maintained, while all other teeth were removed and the anterior implants were rooted. Secondly, the interarch relationships were recorded, while the operator pressed the jaw against a low-viscosity elastomer. During this manipulation, the position of the residual teeth provided occlusal references, while the implant supports were impressed into the elastomer. Thirdly, all posterior teeth were extracted, and the posterior implants were inserted. Finally, the implant positions were recorded using a polyester impression material (Impregum®). The immediate implant-supported prosthesis was made with resin teeth (Orthotype®, Ivoclar). It was inserted on the implants within a period of 48 to 72 h after surgery. The pre- and postoperative dental statuses of each subject are detailed in Table 1. All patients were asked to chew liquid and soft foods during 2 months and then to introduce progressively more textured foods according to their perceptions of their abilities. For the whole group, the mean time (±SD) between the surgical phase and the postoperative evaluations was 131±26 days.

Food samples

Three viscoelastic model foods and two natural foods were used. The three viscoelastic model foods, differing in hardness [soft (S), medium (M), and hard (H)] and normalized in size and shape, were prepared from gummy sweet jelly products, gelatine, and water. The gummy jelly products (105 g) were put in a glass container with gelatin (0 g for S, 4.2 g for M, and 10.5 for H) and water (10 ml for S and M, 20 ml for H), then warmed in a water bath until completely melted giving a homogeneous liquid, then three drops of coloring agents was added to each hardness for easy identification. After 3 min of mix, the blend was poured into Plexiglass cylindrical molds (1 cm height, 2 cm diameter). After the gelling process had stabilized (at least 3 days), 75 cylinders of each hardness were tested using an Instron Universal Testing Machine (Instron mini 55, High Wycombe, Bucks, UK) under uniaxial compression performed at 50 mm/min to a strain of 50 % of initial sample height. Stresses (mean and standard deviation) at 50 % deformation for the three elastic model foods were 70±20 for S, 90±70 for M, and 100±20 kPa for H. A new batch of model foods was prepared for each session. Three standardized samples of carrot (cylinders of 2 cm diameter adjusted in height to reach a weight of 4.0±0.5 g) and non-salted raw peanuts (selected to reach a weight of 4.0±0.5 g) were prepared.

Table 1 Description of initial and final dental/prosthetic status on maxillary and mandibulary arch

Arch	Preoperative dental status		Postoperative dental status	
	Maxillary	Mandibulary	Maxillary	Mandibulary
Subjects				
1	RPD~11 prost-teeth and 3 nat-teeth	RPD~10 prost-teeth and 4 nat-teeth	RPD~11 prost-teeth and 3 nat-teeth	IFP+C on 6 implants
2	IFP-C on 4 implants and 4 nat-teeth	RPD~8 prost-teeth and 4 nat-teeth	IFP-C on 4 implants and 4 nat-teeth	IFP-C on 4 implants
3	RFD	RPD~9 P-teeth and 5 N-teeth	RFD	IFP+C on 4 implants
4	IFP-C on 8 implants	RPD~10 prost-teeth and 5 nat-teeth	IFP-C on 8 implants	IFP-C on 6 implants
5	RFD	RFD	RFD	IFP+C on 6 implants
6	IFP-C on 6 implants	RPD~12 prost-teeth and 2 nat-teeth	IFP-C on 6 implants	IFP-C on 6 implants
7	RPD~8 prost-teeth and 4 nat-teeth	Dentate 13 nat-teeth	IFP-C on 6 implants	Dentate 13 nat-teeth
8	IFP+C on 6 implants	RPD~7 prost-teeth and 7 Nat-teeth	IFP+C on 6 implants	IFP-C on 6 implants
9	RFD	IFP-C on 6 implants	IFP+C on 6 implants	IFP-C on 6 implants
10	RFD	RFD	RFD	IFP+C on 6 implants
11	RPD~11 prost-teeth and 3 nat-teeth	RPD~3 prost- teeth and 11 nat-teeth	IFP-C on 8 implants	RPD~3 prost-teeth and 11 nat-teeth
12	RFD	RPD~10 prost-teeth and 4 nat-teeth	RFD	IFP+C on 6 implants
13	IFP+C on 5 implants	RPD~7 prost-teeth and 7 nat-teeth	IFP+C on 5 implants	IFP-C on 6 implants
14	RFD	RFD	IFP-C on 8 implants	RFD

RFP removable full denture; *RPD* removable partial denture; *Prost-teeth* teeth being counted on a removable partial denture; *dentate* natural teeth (*nat-teeth*), without any removable denture; *IFP* implant fixed prosthesis with (*IFP+C*) or without Cantilever (*IFP-C*)

Experimental procedure

Video recording was used for evaluation of kinematic parameters [28, 29]. A digital camera positioned in front of the subject (face-on) recorded a video of the face. The session began with the mastication of the three viscoelastic model foods, which were presented in triplicate in random order. All subjects were asked to close their eyes while the experimenter placed the food sample on the tongue so as to prevent recognition of the food sample. The subjects then had to close the mouth and teeth without contracting their muscles, keeping the food sample between the tongue and palate. When prompted by the experimenter, the subjects began chewing as naturally as possible.

The subjects were then asked to chew three replicates of carrots and peanuts. The first replicate was completely masticated and swallowed for training. During this sequence, the chewing time was monitored by an investigator and was the baseline time for the following measurements. For the two other replicates, the patient was instructed to spit out each bolus when they thought it was ready to be swallowed. If there was a difference of more than ±5 s between the chewing times of the swallowed and the two expectorated replicates, the patient was asked to chew a new piece of the test food.

Food refusals

Each occasion a subject refused to test the food sample and each time a subject spat the sample out before the end of the first chewing cycle were registered as a food refusal.

Bolus granulometry analysis

Each chewed bolus (masticate) was collected in a container, rinsed with water in a 100-μm sieve to eliminate saliva, and dried at 80 °C for 30 min. The bolus was then spread onto a transparent A4 sheet. The sheet was scanned to produce a 600-dpi image. The images were then software-processed to evaluate food particle size and distribution (Powdershape®, Innovative Sintering Technologies, Switzerland). For each masticate, the results were expressed in terms of the D50 value, characterizing the theoretical sieve size that would let through 50 % of the particle weights [19, 30]. Thus, D50 value decreased as food boluses contained more small particles. According to a previous study, the two D50 values recorded for each subject and each natural food were averaged, and D50 values for carrots above 4 mm were considered as coming from a subject with impaired mastication [19].

Kinematic parameters of mastication

The evaluations of each kinematic parameter required an independent reading of each video recording by a calibrated observer who watched the recordings in random order. The method has previously been validated for healthy, fully dentate patients and for denture wearers [28, 29]. The recorded variables were chewing time (CT: the time in seconds between the moment where the subject started to chew and swallowing, identified by the immediate swallow after the end of rhythmic rotary movements) and number of chewing cycles (CC: number of chewing actions during the CT period; this included all the rotary patterns, with and without lip closure). Chewing frequency (CF) was calculated as the ratio CC/CT.

Oral health quality of life

Geriatric Oral Health Assessment Index (GOHAI) is a questionnaire on oral health quality of life (QoL) [31]. It comprises 12 items grouped into three fields: (1) the functional field (eating, speaking, and swallowing), (2) the psychosocial field (concerns, relational discomfort, and appearance), and (3) the pain or discomfort field (drugs, gingival sensitivity, and discomfort when chewing certain foods). A score of 57 to 60 is regarded as high and corresponds to a satisfactory oral QoL. A score from 51 to 56 is regarded as average, and a score of 50 or less is regarded as a low score, reflecting a poor oral QoL. A validated French version was used [32].

Statistical analysis

Statistical analysis was performed using IBM SPSS®19 software. ANOVA was undertaken on mean CC and CT values to assess variations with jelly hardness either before or after rehabilitation. A post hoc Student–Newman–Keuls test (SNK) was applied when ANOVA displayed significant variations. Statistical significance was set at $p<0.05$.

To evaluate the impact of ILFAP rehabilitation on mastication parameters, the mean values of CC, CT, and CF measured during mastication of carrot and peanuts and of viscoelastic test foods were compared before and after treatment by three repeated model procedures (RMP) (dependent factor: CC, CT CF; fixed factor: hardness of model food). The same analysis was performed for carrot and peanuts (dependent factor: CC, CT, CF and D50; fixed factor: food type (carrots or peanuts).

The mean values of the GOHAI scores recorded before and after rehabilitation were compared by paired sample t test. Values were expressed as mean±SE except when expressed otherwise.

Results

Food refusals and bolus granulometry

Before rehabilitation, two subjects refused to chew both carrots and peanut samples, while no refusal was noted after

ILFAP rehabilitation. The mean D50, CC, CT, and CF values measured for carrot and peanuts before and after ILFAP rehabilitation are presented in Table 2. The mean D50s were significantly decreased after rehabilitation for carrot and peanuts (RMP, F=41, p<0.001). The distribution of the mean D50 values for carrot recorded before and after rehabilitation for each subject is shown in Fig. 1. Before rehabilitation, all subjects had a mean D50 value above or near the MNI value of 4,000 μm. After rehabilitation, the mean D50 value was included in the range of normality for 11 subjects. This decrease in D50 was achieved in spite of a significant decrease in CC and CT for both foods (RMP, F=11, p<0.001) after rehabilitation. No significant changes were observed for CF.

Chewing adaptation to food hardness

Before rehabilitation, the mean values of CC and CT for the three model jellies did not differ according to the food hardness, while CC (F=16) and CT (F=17) increased slightly with food hardness after rehabilitation (p<0.001; ANOVA followed by SNK; Fig. 2). When comparing mean values of CC, CT, and CF, controlling for subject before and after rehabilitation, significant decreases in CC and CT mean values (Fig. 2) were shown, while CF increased significantly from 1.43 to 1.47 cycles/s. These variations were independent of the hardness factor (RMP procedure, F=14 for CC, F=10 for CT, and F=11 for CF; p<0.001).

Quality of life related to oral health

Compared with the preoperative values, the mean GOHAI scores were significantly increased after ILFAP rehabilitation in all the functional, comfort, and psychosocial fields that make up the GOHAI-Add score (Table 3). The item on difficulties biting or chewing foods was characterized by the highest variations (from 2.3±1.3 to 4.6±0.7).

Table 2 Mean values (±SD) of the granulometry of the carrot and peanut preswallowed bolus (D50, median size of bolus particles) and kinematics parameters to produce this bolus (CC, number of chewing cycles; CT, chewing time; CF, chewing frequency with CF=CC/CT) before and after ILFAP rehabilitation in the study group

		Before rehabilitation	After ILFAP rehabilitation
Carrot	D50 (μm)	4,830±1,013	3,292±1,335
	CC	62.4±32.9	55.7±19.6
	CT (s)	39.8±21.2	34.8±12.7
	CF (s^{-1})	1.62±0.24	1.62±0.21
Peanut	D50 (μm)	3,918±897	2,611±1,112
	CC	76.0±49.0	58.3±20.0
	CT (s)	47.7±29.6	36.2±12.7
	CF (s^{-1})	1.62±0.21	1.63±0.18

Discussion

This study is the first that uses physiological parameters to demonstrate an effective improvement of mastication after rehabilitation of one full arch with immediate loading implants. Patients who received ILFAP rehabilitation improved their ability to reduce the bolus particle size and their ability to discriminate between different food hardnesses. Moreover, the quality of life in relation to oral health was greatly improved. This demonstrates that oral rehabilitation with ILFAP has led to a functional readaptation in the 6 months post-surgery period.

Before rehabilitation, the observed subjects had impaired mastication, as shown by: (1) a poor final end result of the masticatory function, shown by the MNI values above the cutoff for most patients; (2) inability to adapt chewing to food properties, demonstrated by the lack of change in CT and CC despite an increased hardness of model foods; (3) chewing difficulties suggested by the low CF; and (4) food refusal in two patients. The physiological incapacities in chewing function were perceived by the patients as demonstrated by the low scores in the functional field of the GOHAI score. The poor oral status present before oral rehabilitation explains this masticatory deficiency. This is similar to previous observations in subjects with periodontitis [33–35], in complete denture wearers who had difficulty chewing natural foods [23, 25] or model foods with increasing hardness [24], or in persons with neurological deficits [28, 36, 37].

The present data refute the hypothesis of proprioception-related impairment of mastication following ILFAP treatment. On the contrary, it demonstrates that ILFAP allows the recovery of a healthy masticatory function within 6 months. This was shown by the four following points: (1) A decrease in bolus granulometry, as evidenced by D50 values below the MNI cutoff for most patients; (2) The ability to adapt to food properties was restored; the kinetic parameters (CT and CC) varied according to hardness; (3) The increase in CF strongly suggested a reduction or the disappearance of chewing difficulties; and (4) No participant refused food. It was not possible to compare directly with persons with normal masticatory function since the study design did not include a control group with healthy dentate participants. It is interesting to compare the post-ILFAP rehabilitation data with the results obtained in subjects with full natural dentition using granulometry [30]. The D50 values were slightly higher in ILFAP patients than in patients with full natural dentition (respectively 3,292±1,013 versus 2,598±651 μm for carrots and 2,611±111 versus 1,690±320 μm for

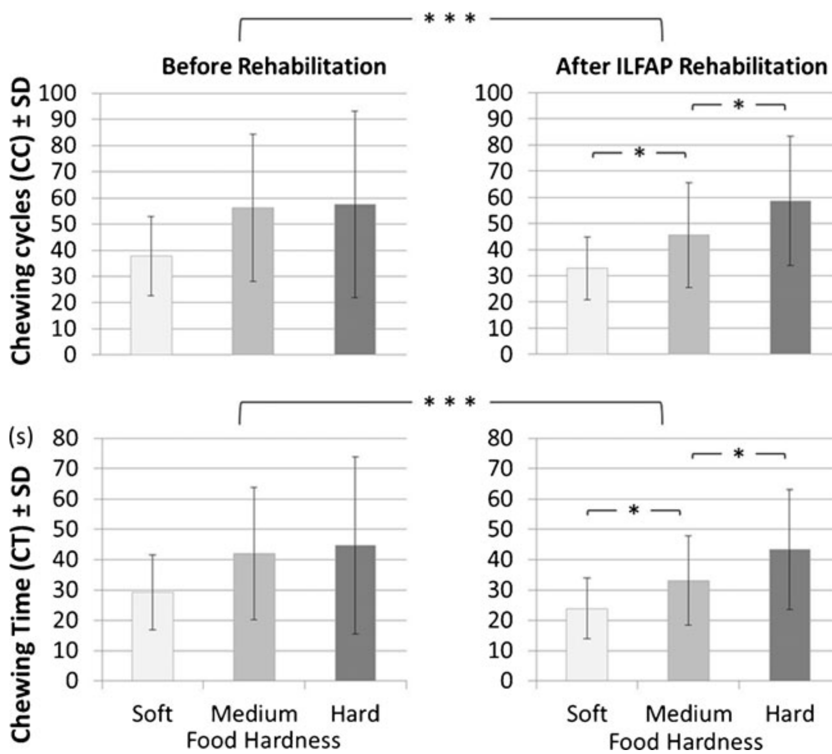

Fig. 1 Mean numbers of chewing cycles (±SD) and mean chewing time (±SD) required to chew three jelly samples differing in hardness before and after ILFAP rehabilitation for the study group. Intragroup comparisons were made with post-ANOVA SNK (* $p<0.05$); Repeated measure procedure was used for intergroup comparisons (*** $p<0.001$)

peanuts). Although direct comparison between these two studies may be debatable, these differences may be explained by the small number of implants in ILFAP patients compared with the number of natural teeth in fully dentate patients. Incomplete reinnervation 6 months after implantation is also a possibility.

The present data extend to ILFAP the results obtained in the past with implant retained complete dentures. The improvement in mastication by implant-supported dentures was already demonstrated by measurement of different variables such as the food bolus particle size [16, 38], kinematic and electromyographic parameters [39, 40]. The improvement given by implant-supported dentures was also previously confirmed by the questionnaire on quality of life and other methods for self-assessment of mastication [16, 41–44]. Although the improvement in masticatory function appears to be well established, there is evidence that it is not complete [18, 39, 45, 46]. Two studies evaluated the duration over 5 to 10 years of the improvement in masticatory function induced by implant rehabilitation. A progressive change was noted in one study [47] and no change in another [40]. The follow-up of our patients with a longitudinal approach will give more information about the evolution of the masticatory function and oral health self-evaluation after ILFAP treatment.

The comparison of the impact on the adaptability of immediate loading with conventional mediated loading can

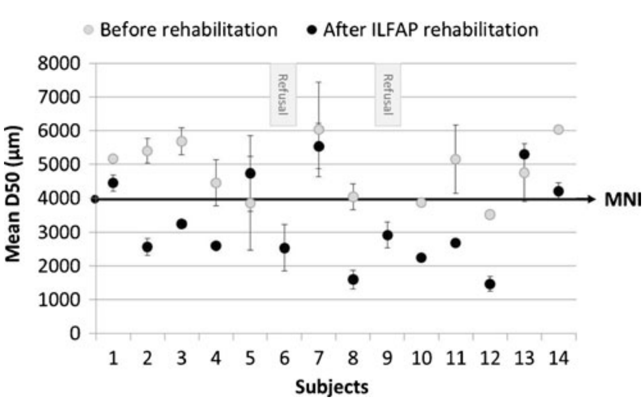

Fig. 2 Distribution of the mean individual D50 values (±SD) measured for carrot bolus before and after ILFAP rehabilitation. MNI (Masticatory Normative Index) values represent the cutoff value above which subjects have impaired mastication [19]

Table 3 Comparisons of the mean GOHAI score values before and after ILFAP rehabilitation for the study group

	Preoperative Scores±SD	Postoperative Scores±SD	Comparisons (Paired *t* test, *p* values)
Functional fields (max, 20)	13.4±3.8	18.6±1	$p<0.001$
Comfort fields (max, 15)	11.5±2.1	14.5±0.9	$p<0.001$
Psychosocial fields (max, 25)	16.5±4.4	22.6±2.6	$p<0.05$
GOHAI-Add (total)	43±9	56±3	$p<0.001$

be discussed on the basis of a recent study [22]. For the first time, this 12-month follow-up study evaluated the adaptability of mastication in a group of subjects receiving implant-supported bridges with a conventional 2-month post-surgery loading. Model foods of different hardness were also used, and electromyographic activity, the number of chewing cycles, chewing sequence duration, and other kinematic parameters were measured. This study showed that people with implant-supported bridges recovered the ability to adapt to an increased hardness of the model foods. Therefore, the comparison between the two studies suggests that immediate loading after implantation improves the adaptability of mastication as well as conventional 2-month post-surgery loading, but both studies suggested that the recovery in masticatory function was not complete. After conventional 2-month post-surgery loading, magnetic-based kinematic recordings showed that increase in jaw opening velocity, vertical and lateral amplitude of chewing movements with food hardness did not occur. Electromyographic activity also showed that the increased adaptation to hardness was reduced compared with fully dentate control subjects. Similarly, five patients in our study still had D50 values above the cutoff value of 4 mm after ILFAP. Further longitudinal clinical studies are required to verify the hypothesis of incomplete healing after implant-supported fixed rehabilitation with either conventional or immediate loading procedures.

In conclusion, this study demonstrated a clear benefit in terms of masticatory ability shown by the reduction of the D50 of food boluses before swallowing, the decrease in chewing time and the number of cycles, the increased chewing frequency, and the absence of food refusal. This study encourages the clinical development of immediate loading implantation with fixed full-arch prosthesis protocol. Other experiments should be carried out to determine the factors implicated in the incomplete recovery of the masticatory adaptation ability.

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Conflict of interest The authors declare they have no conflicts of interest.

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