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APPLICATION OF BIOACTIVE CERAMICS FOR FUNCTIONAL SURGERY IN MASTICATORY ORGANS

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Abstract—Transplanted and replanted autogenous teeth or implanted artificial roots become easily ankylotic. However, if adequate functional loads are applied to them continuously postop with proper fixation, ankylosis can be prevented. The author found this fact through studies on autogenous tooth replantation 20 years ago. Therefore, not only can tooth transplantation, replantation, and artificial root implantation be done successfully with adequate functional loads, but surgical orthodontics as well as plastic operation of jaw deformity can also benefit in the same way. This therapeutic method is called functional surgery. The ankylotic process can be more effectively prevented by applying bioceramic granules. Using these methods, (a) 30 vital teeth in 23 patients were transplanted or replanted. Follow-up duration was 6 to 96 months. (b) Artificial roots made of compact sintered hydroxyapatite (apatite) were implanted under the new concept of functional surgery. In all, 57 artificial roots in 19 patients were implanted and observed for over 5 years. (c) Masticatory skeletal deformities of the viscerocranium were treated with the new concept of functional surgery applying sintered apatite. For this purpose, artificial bone implantation or simple gnathoplasty, tooth transplantation, and artificial root implantation was carried out in 15 patients, after which mastication training was applied with concomitant corrections of function inclination, i.e., oral-perioral habits. In these clinical experiments, excellent favorable results were obtained.

The following conclusion was obtained: Introducing the new concept of functional surgery using bioceramics, not only tooth transplantation, as well as artificial root therapeutics, but deformity of the jaw can be steadily treated.

Key Words—functional surgery, transplantation, ankylosis deformity, oral-perioral habits

INTRODUCTION

A NEW concept of functional surgery in the masticatory organ is introduced in this paper. The concept of functional surgery, i.e., adequate postoperative functional load application instead of the usual tight fixation in skeletal reconstructive operation, was applied with the aid of sintered hydroxyapatite for (a) autogenous vital tooth transplantation (replantation) (1), (b) artificial root therapeutics (2), and (c) masticatory skeletal deformity (3–5). For over 100 years, tooth transplantation has been attempted unsuccessfully because of root resorption caused by ankylosis. Transplanted (replanted) autogenous teeth or implanted artificial roots always became ankylotic, if they were fixed by the usual skeletal therapeutic method (6). However, if adequate functional loads are continuously applied to them immediately after operation with proper fixation instead of conventional concrete fixation, ankylosis can be prevented and they can function long-term. The author found this fact through studies on autogenous tooth replantation (1).

Therefore, not only can tooth transplantation, replantation, and artificial root implantation be done successfully with adequate functional loads, but surgical orthodontics as well as plastic operation of jaw deformity can also benefit in the same way (4,5). This therapeutic method is called functional surgery. The ankylotic process can be more effectively prevented by applying bioceramic granules (1,3,5). Using these methods, 30 teeth in 23 patients were transplanted or replanted, and favorable results were obtained. From a biomechanical point of view, the tooth and jaw bone system, i.e., skeletal system in the viscerocranium, is quite

different from any other part of the human skeletal system. Mastication is a unique system in mammals, in which the tooth has an important role to bear multiple masticatory forces. The mastication can be carried out only by gomphotic teeth. Artificial roots made of compact sintered hydroxyapatite (apatite) were applied clinically with this new concept of functional surgery (2,6,7). By doing so, inducement of periimplant supportive tissue can be obtained resembling periodontal ligament and alveolar bone proper around the artificial roots (8–11). Fifty-seven artificial roots in 19 patients were implanted and observed for over 5 years. Good results were obtained.

Bone morphology and shape of dentition (dental arch) can be transformed according to functional inclinations (5). Therefore, before and after surgery in the viscerocranium, remedy of junctional inclination, i.e., habit correction as well as application with proper function is essential (5). Masticatory skeletal deformities of the viscerocranium were treated with the new concept of functional surgery using sintered apatite (5). For this purpose, tooth transplantation, artificial root implantation, artificial bone implantation, or simple gnathoplasty was carried out in 15 patients, after which mastication training was applied with concomitant corrections of functional inclination, i.e., oral-perioral habits (5). By such therapeutics, deformities of the viscerocranium including edentulous jaws could be easily and steadily recovered. The new concept of functional surgery in the masticatory organ using bioceramics includes: (a) Before and after surgery, functional inclination around the mandible, i.e., oral-perioral habits, are corrected to avoid lateral mechanical forces to the tooth or functional inclination to the bone (5). (b) After the operation, concrete fixation or too long fixation of the masticatory organ is avoided. (c) Immediately after the operation, adequate biomechanical stimulation is applied to the masticatory organ to prevent inadequate ankylosis (1,4). (d) After surgery, symmetrical (balanced) functional training is applied to avoid functional inclination to the bone, which causes transformation of the mandible (5).

In this clinical experiment, excellent results were obtained. Dense apatite artificial roots and porous apatite artificial bones (block) and granules are useful for functional surgery in the masticatory organ. Through occlusal functions, apatite granules around the dental (artificial) root are covered with connective tissue by micromobilities (Fig. 1). The gingival epithelium attaches to the sintered dense hydroxyapatite surface of artificial root and apatite granules prevent ankylosis of the roots, recovering microcirculation around the operation site (Fig. 1).

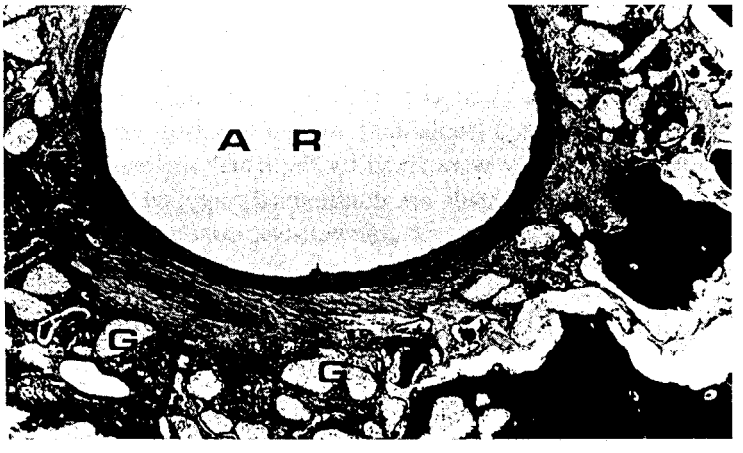


FIG. 1. Hydroxyapatite granules around artificial root applied at implantation (2 months). Granules were covered with collagen fibers without ossification.

PATIENTS AND METHODS

Transplantation or replantation of vital teeth, artificial root implantation, and treatment of jaw deformities were all carried out using sintered hydroxyapatite. After postoperative fixation was done, proper functional loading and mastication training were applied in all cases, so as to induce periodontal supportive tissue and develop symmetrical jawbone (5,12). For tooth fixation Super Bond (Sunmedical Co. Ltd., Kyoto) was used.

1. Twenty-three healthy patients were provided with vital tooth replantation and transplantation with the aid of apatite porous granules (Apaceram G: Asahi Optical Co. Ltd., Tokyo). Vital tooth transplantation was carried out with cutting of the root apex about 1 mm in length to support circulation of the pulp. Of 23 patients with 31 teeth, 9 teeth were transplanted, 7 were replanted, and 14 were surgically repositioned. The follow-up durations spanned from 7 to 96 months. Replantation was provided for impacted teeth.
2. Newly tailored artificial roots made of dense sintered hydroxyapatite with undulated conical configuration were fabricated in Asahi Optical Co. Ltd. Fifty-seven artificial roots were implanted in 19 patients aged 30 to 72 years. Forty artificial roots were implanted in free-end edentulous cases. Seventeen artificial roots were implanted in intermediate cases.
3. Fifteen healthy patients aged 18 to 60 years (8 females and 7 males) with jawbone deformities were treated to recover the deformities by mastication training, implantation of hydroxyapatite block (20% porosity, Asahi Optical Co. Ltd., Tokyo) artificial root therapeutics, surgical minor tooth movement and transplantation with the aid of apatite granules. Two cases of apatite block implantation, 4 cases of transplantation or replantation (8 teeth), 3 cases of surgical orthodontics (8 teeth), 4 cases of artificial root (10 roots), and 2 cases of gnathoplasty were carried out.

RESULTS

Vital Tooth Transplantation (Replantation)

The age distribution of the patients is shown in Table 1. These transplanted or replanted vital teeth were observed from 7 to 96 months. Three of them were necrotic in pulp, while the others were in good function. Two teeth were absorbed slightly in the root. In the other cases, no marked root resorption could be seen.

Artificial Root Therapeutics

The age distribution of the patients is shown in Table 2. The longest follow-up of cases at the present time has lasted over 76 months. One patient died from angina pectoris 4 years after implantation. Four artificial roots were extracted due to inflammation. Among 54 artificial roots in 18 cases, 50 artificial roots (93%) have been functioning. Periodontal

Table 1. Age Distribution

Age	10	20	30	40	50	60	Total
Male	0	6	0	2	2	0	10
Female	2	4	1	3	2	1	13
Total	2	10	1	5	4	1	23

Table 2. Age Distribution

Age	10	20	30	40	50	60	70	Total
Male	0	0	0	1	6	0	0	7
Female	0	0	3	5	1	2	1	12
Total	0	0	3	6	7	2	1	19

inflammation, which was recovered by treatment, was observed around four artificial roots 3 years postop.

Masticatory Deformity Treatments

The age distribution is shown in Table 3. To recover jawbone deformity, the following cases were treated: Two cases of apatite block implantation, transplantation of 12 teeth (including replantation of 8 teeth), 3 cases of surgical orthodontics (8 teeth), 4 cases of artificial root therapeutics with alveolar bone augmentation (10 artificial roots), and 2 cases of gnathoplasty. By these treatments, structural defects were recovered. Before operation, remedy of oral-perioral habits (functional inclination) was carried out, and mastication training was applied postoperatively; therefore, deformities were effectively recovered. No marked trouble was observed in any case. Representative cases are presented (Figs. 2, 3, 4).

DISCUSSION AND CONCLUSION

Tooth transplantation and replantation have been attempted unsuccessfully for 100 years. Tooth root resorption has been the most serious postoperative problem. Therefore, transplantation has been an unreliable method to restore occlusal function. Root resorption can be classified into three categories (3,13): (a) Surface resorption in the cementum and outermost layers of the dentine, (b) replacement resorption by ankylosis, and (c) inflammatory resorption in relation to inflammation in the periodontal membrane.

The important issues concerning root absorption are inflammatory and replacement resorption. The author noticed that replacement resorption resulting from ankylosis occurs by complete fixation of the recipient teeth, while inflammatory resorption occurs through mobility of the recipient tooth by traumatic occlusion, which causes periodontal infection. Therefore, tooth replantation or transplantation can be applied successfully by proper physiological movement of the tooth, i.e., neither too strong, nor too weak, which prevents ankylosis or traumatic occlusion due to too tight or too loose fixation (1).

Reinforced autogenous tooth replantation was observed for about 20 years (1). Through these observations, the author found that proper physiological mobility of the replanted tooth could be easily attained by encouraging mastication without too tight occlusal bite of the recipient tooth shortly postop. Proper mobility is relevant to physiological movement of the healthy tooth and can be easily accomplished through plastic adhesive with adjacent teeth or through adjacent one-sided tooth fixation with the replanted tooth by a sequential crown. Through this simple method, we can resolve the serious problem that affected and disturbed

Table 3. Age Distribution

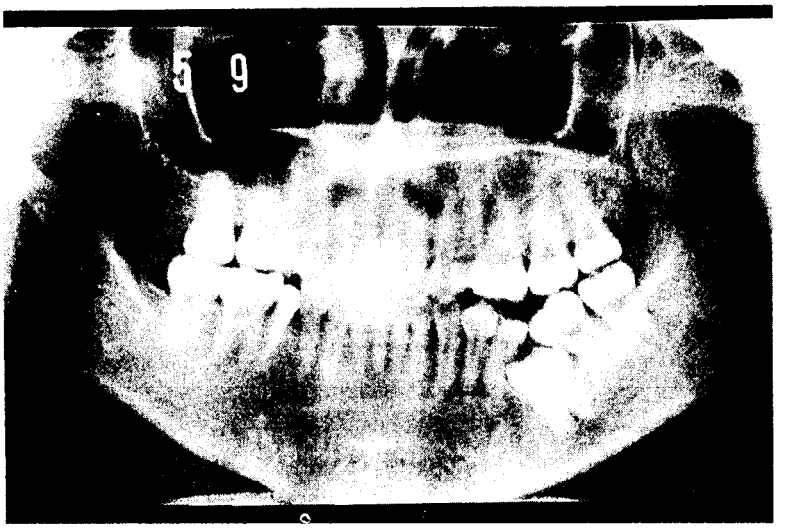
Age	10	20	30	40	50	60	Total
Male	0	3	0	1	2	1	7
Female	2	1	2	1	0	2	8
Total	2	4	2	2	2	3	15

FIG. 2. Porous hydroxyapatite plate was implanted to recover alveolar bone for artificial root therapeutics.

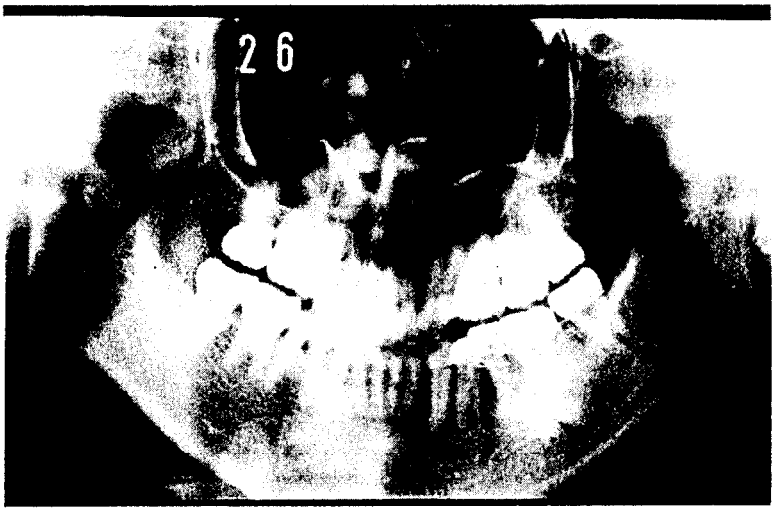
tooth transplantation therapy for the past 100 years. With sintered hydroxyapatite granules, tooth replantation therapeutics can be more easily accomplished. Even with intact pulp, we can transplant an autogenous tooth successfully. Through the sintered hydroxyapatite material effect, even the narrow pulp blood supply is assumed to recover (5,14). This fact can be explained by the results of hydroxyapatite granule application in the dental pulp chamber (14). Tissue and blood vessel regeneration with calcified tissue can be observed in the chamber, where tissue was completely removed (Fig. 5). Of these transplantations, replan-

(a) (b)

FIG. 3. (a) 19-year-old female with left unilateral mastication habit. (b) Remedy of habit, transplantation of two vital teeth and simple gnathoplasty were carried out (2-years postop).



(a)



(b)

(c)

FIG. 4. (a) 28-year-old female with lateral (left side) sleeping posture habit. Left molar with filling was submerged. (b) Three teeth were removed and two of them were repositioned with hydroxyapatite granules. (c) Two teeth were replanted with vital condition (2-years postop).

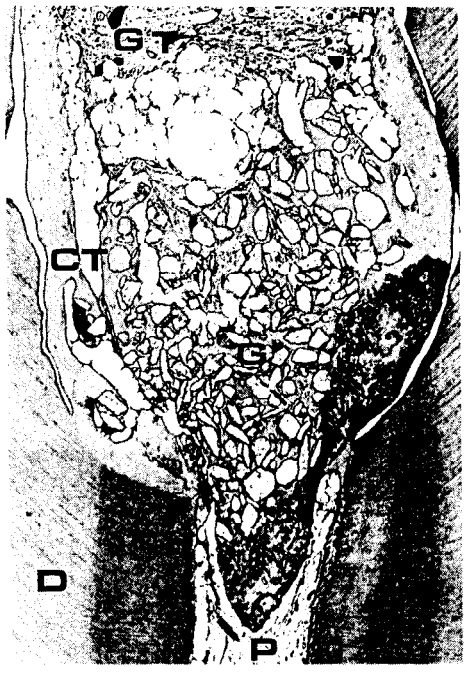


FIG. 5. Hydroxyapatite granules in dental pulp chamber. Dental pulp was removed completely at crown portion. Then hydroxyapatite granules were applied and covered with hydroxyapatite cement. Five-month postop specimen was made (human tooth).

tation, and surgical repositioning orthodontics, the most drastic and useful treatment is reimplantation of an extruded mobile tooth affected by advanced marginal periodontitis. Even such a progressive case can be recovered with this method (1) (Fig. 6 a–d). This fact means marginal periodontitis can be recovered in any case, if we can manage to control certain factors that destroy the tooth-supporting system. The criteria are whether it is possible to (a) eliminate the structural defect of dentition, (b) remove tooth-swaying movement by a removable denture or to correct perioral habits by which lateral stress to the teeth occurs, (c) make a fresh rough root surface for tissue reattachment, (d) obtain stabilization of the affected tooth and postop fixation, and (e) maintain good oral hygiene. If we can accomplish these criteria completely, we can surely cure marginal periodontal conditions regardless of the grade of severity.

The phenomenon of replacement absorption of the tooth root is very important to be solved. The phenomenon can be understood as follows: After a solid state, ankylosis between tooth root and bone has occurred, and bone remodeling around the root continues just at the same rate as osseous tissue. However, the tooth root dentine has no original remodeling system. Therefore, once ordinal bone remodeling starts, osteoclastic resorption of bone and root occurs. The tooth root dentine should be remodeled and replaced with osseous tissue. After that, the tooth root disappears and replacement resorption can be seen. Then what about the ankylosis between osseous tissue and biomaterials? In this condition, the problem is also one-side remodeling of the bone. At the junction site, bone tissue can remodel to contact with biomaterials again, if the biomaterials have no marked loading. However, under severe repeated loading, disruption of ankylosis occurs because of differences in elastic moduli of bone and bioceramics. Then the interface cannot reattach to make ankylosis by stress concentration in the boundary. Thus the ankylosis or osseointegration between bone and biomaterials cannot stand up under severe repeated loading.

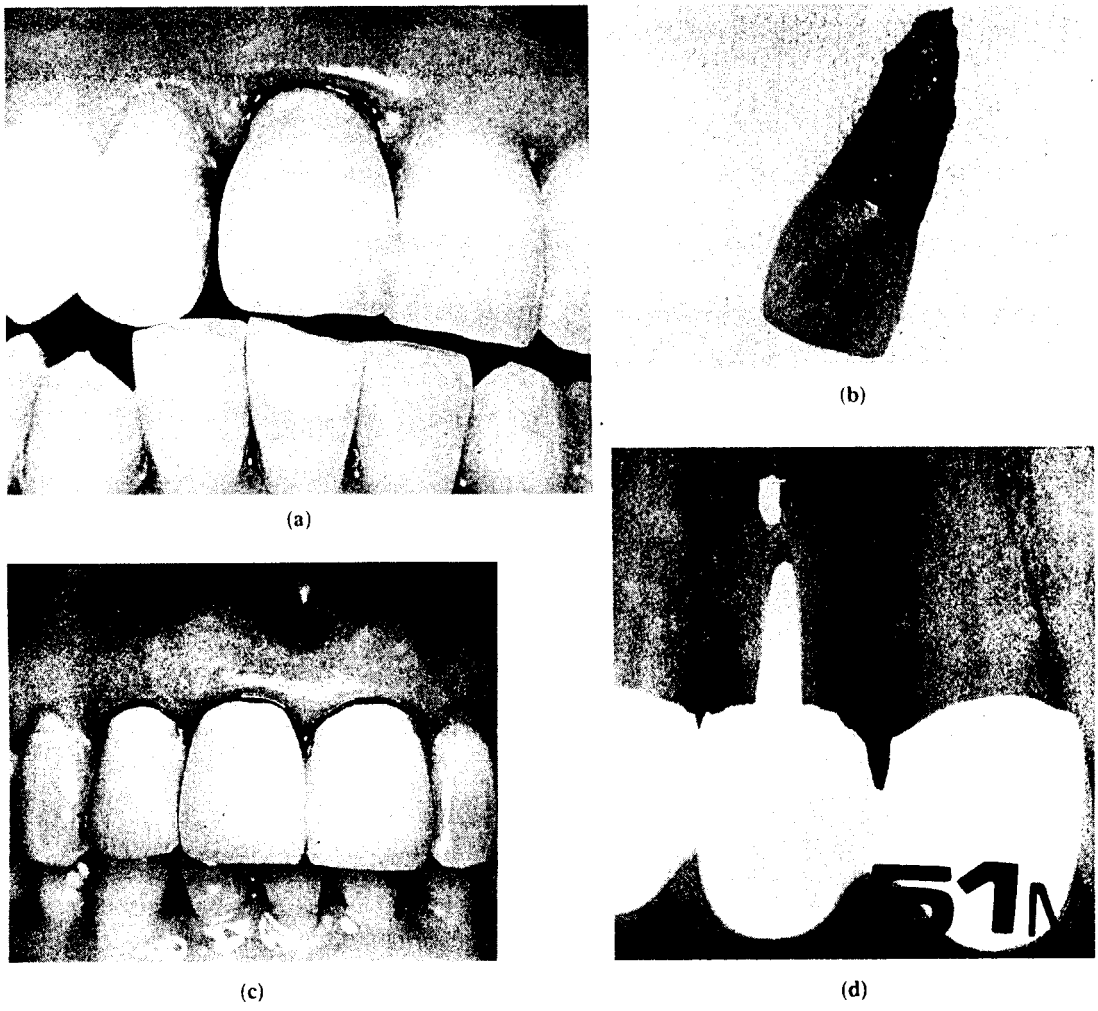


FIG. 6. Forty-five-year-old female with severe periodontitis in incisor and molar regions. Diastema in upper incisors and disrupted occlusal plane between lower incisors and canine were observed. These are thought to result from lateral sleeping posture habit causing deformity of mandible. (a) Periodontal pocket was observed 7 mm in depth. (b) Infected tooth was extracted. Root surface was shaved to expose intact dentine. Then tooth was replanted with hydroxyapatite granules in socket of which bottom was deepened by grinding. (c) Six years after operation. (d) Fifty-one months after replantation. No marked root resorption is observed.

Instead of static condition by fixation, postoperative moderate functional application is essentially important in masticatory organs. Such therapeutics is called functional surgery in masticatory organs. From this standpoint, the author has developed a new type artificial root made of dense sintered hydroxyapatite. Clinical studies were carried out successfully with the newly tailored artificial roots (2,6,7). Applying the concept of functional surgery, the tooth supportive structures around the root, i.e., the alveolar bone proper and ligamentous fibers, developed satisfactorily (9–11).

The author revealed the biomechanical properties of the tooth by finite element analyses (15,16). The results indicate that the tooth is a vehicle of masticatory multiple forces by which stresses are dispersed in the jawbone, and principal stress trajectories are converted parallel and orthogonal to the root surface through periodontal ligaments (15,16). Thereafter, the stresses are borne by the cortices of the jaws. From this aspect of the biomechanical system of the tooth, a few numbers of teeth can be moved by simple corticotomy with intact

dental pulp. Clinical studies were successfully carried out. Apatite granules were effective in regenerating blood vessels and in preventing undergrowth of the epithelium (1). The aforementioned therapeutics was combined and applied to recover jawbone deformity.

The shape of the dental arch and morphology of the bone change gradually according to the functional inclination and unbalanced applied force within the bounds of inherency (5). Thus, long-term functional inclination essentially evokes biomechanically structural defects of dentition or transformation of the jawbone. This phenomenon can be explained by Wolff's law of functional transformation of the bone (17–23). From this viewpoint, functional surgery is important for masticatory skeletal deformity. These transformations have a close relation to oral disease in some cases. Namely, a functional inclination of the jaw can have a relation to some oral diseases. The functional inclination can be summarized as oral-perioral habits (5). Oral-perioral habits affect biomechanical forces to the masticatory organ. Therefore, for the treatment of jawbone deformity and for orthodontics, remedy of the habits is the most important. For the application of bioceramics, remedy of biomechanical forces is also important (5). By the new concept of functional surgery, structural defect of the masticatory organ was treated and good results were obtained. From these clinical studies, the following conclusions were obtained: (a) Root resorption can be mostly prevented by applying functional surgery. (b) Root supportive structure around the dental implant can be induced by such therapeutics. (c) Jawbone deformity can be effectively treated by this method.

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