RESULTS OF THE STUDY OF ALKALINE PHOSPHATASE ACTIVITY AFTER DENTAL IMPLANTATION

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ABSTRACT

Assessment of biochemical markers in oral fluid provides a non-invasive approach for monitoring bone metabolism and osseointegration processes following dental implantation. This study aimed to evaluate the dynamics of enzymatic biomarkers involved in bone remodelling, particularly alkaline phosphatase (ALP) and tartrate-resistant acid phosphatase (TRAP-5b), in patients after dental implantation. The study included patients who underwent dental implantation, with enzymatic activity assessed in oral fluid samples and compared with a control group of individuals without implantation. Alkaline phosphatase and tartrate-resistant acid phosphatase activities were analyzed at different postoperative time points to assess the progression of osseointegration-related metabolic processes. The analysis demonstrated that alkaline phosphatase activity did not show statistically significant changes over the observation period, indicating relatively stable or weak osteoblastic activity. In contrast, tartrate-resistant acid phosphatase levels increased markedly in the early postoperative period, reflecting enhanced osteoclastic activity and inflammatory response. A gradual decrease in TRAP-5b activity was observed at later stages, corresponding to attenuation of resorptive processes and progression toward bone tissue remodeling and maturation. The findings indicate that tartrate-resistant acid phosphatase is a sensitive marker of early inflammatory and resorptive processes following dental implantation. In contrast, alkaline phosphatase reflects longer-term stabilization of bone metabolism. Combined assessment of these enzymatic biomarkers may be useful for monitoring osseointegration dynamics and evaluating postoperative bone remodelling.

Key words: Dental implantation, Osseointegration, Alkaline phosphatase, Tartrate-resistant acid phosphatase, Bone metabolism.

Introduction

A key factor determining the success of dental implantation is fully achieving osseointegration with the bone tissue surrounding the implant. The scientific literature pays considerable attention to this aspect, emphasizing that the quality of the osseointegration of dental bone tissue is largely determined by the level of stabilization in the primary implant [1]. Quantitative changes in the biochemical parameters of oral fluid are observed in cases of inflammatory processes in the oral cavity. In the case of inflammatory processes in the oral cavity, they are observed. Analysis of the literature data indicates that monitoring can be evaluated only on the basis of biochemical parameters for the dynamics of mica, systemic pathological processes in the body, and ho. For example, after dental implantation, increased alkaline phosphatase activity is observed, and mica is not acidic, which violates osseointegration and bone remodeling [2].

At the healing stage, the inflammatory runner phase is activated, accompanied by the release of pro-inflammatory cytokines and growth factors, and by the non-activation of osteoclasts. Increased bone resorption in the osteotomy area

prepares microenvironments for new bone tissue formation. Angiogenesis plays an important role in this process: the formation of a new vascular network is not necessary for nutrient and oxygen delivery to the implantation site. Studies show that when the blood supply to bone tissue is disrupted, trophic conditions significantly worsen, leading to osseointegration and capsule formation around the implant, regardless of whether the fibrosis is fibrotic [3]. It is especially important to maintain microcirculation in conditions of increased mechanical insufficiency, bone loss, or limited graft volume atrophy. Enzymatic markers such as alkaline phosphatase (ALP) and tartrate-resistant acid phosphatase (TRAP) are used to assess bone remodeling activity. It is considered an ALP marker that attracts significant osteoblastic activity and reflects bone mineralization processes in the matrix [4]. On the contrary, it indicates the activity of osteoclasts and the processes of TRKF resorption in bone. According to several authors, during the early post-implantation period, TRKF levels increase by 2-3 times the initial values. The presence of pronounced osteoclastic activity, driven by the initial inflammatory reaction, is not significant, as it does not engage or stimulate many of the initial and remodeling processes. During this period, the level of alkaline

phosphatase, as a rule, remains stable or shows only slight fluctuations, indicating that osteoblast regeneration is gradually progressing [5].

Bone trophies also affect the morphological characteristics of the bone (according to the Lekholm & Zarb classification), the presence of systemic diseases (osteoporosis, diabetes mellitus), and the method of its installation during primary and implant stabilization. In conditions of bone tissue deficiency, additional technologies (augmentation, directed bone regeneration) are used, which require a longer period of trophic stabilization [6]. Thus, the success of dental implantation largely depends on restoring bone tissue to a fully functional state, which is ensured by a balanced interplay among cellular regulation, microcirculation, and biochemical factors. The use of complex diagnostics, including biochemical markers of C (ALP, TRKF), can serve as a valuable tool for monitoring osseointegration and early detection of a violation. The main aim of this study is to determine the features of dental implantation processes in oral fluid, assess the dynamics of alkaline phosphatase activity after implantation treatment, and evaluate the treatment's effectiveness.

Materials and Methods

Study design and participants
This prospective study included 70 patients aged 45 to 50 years who presented to dental clinics for planned dental implantation. All participants were clinically examined before inclusion. Patients were enrolled if they had no systemic diseases affecting bone tissue metabolism, including osteoporosis or hyperparathyroidism, showed no clinical signs of active periodontitis, and had clear indications for dental implant placement. The control group consisted of patients aged 50 years or less with physiological biochemical parameters of oral fluid before implantation.

Ethical considerations
The study protocol was reviewed and approved by the Ethical Committee of Osh State University (Osh State University). All research procedures were conducted in accordance with the ethical principles outlined in the Declaration of Helsinki (Declaration of Helsinki). Written informed consent was obtained from all participants before their inclusion in the study [7].

Study timeline and sample collection
Biochemical assessments were performed dynamically at baseline before implant placement and subsequently at 7, 14, and 28 days, as well as at 3 and 6 months after dental implantation. Oral fluid samples were collected in the morning after fasting to minimize variability due to food intake. The collected biological material was handled and processed immediately in accordance with established laboratory protocols.

Biochemical analysis

The activity of alkaline phosphatase (ALP) in oral fluid was determined using a spectrophotometric method based on enzymatic hydrolysis of phosphoric acid esters. Measurements were performed using the Stat Fax 4500 biochemical analyzer (Awareness Technology) at 405 nm, with an optical path length of 1 cm and a reaction temperature of 37 °C. The baseline ALP activity in oral fluid before dental implantation ranged from 15 to 30 U/L. The activity of tartrate-resistant acid phosphatase 5b (TRAP-5b) was assessed using an enzyme-linked immunosorbent assay with the BoneTRAP Assay kit (IDS, UK). Optical density was measured at 405 nm according to the manufacturer's instructions.

Laboratory conditions
All biochemical analyses were carried out at the Biochemical Laboratory of the Osh Inter-regional United Clinical Hospital, which is equipped with modern analytical instrumentation. Spectrophotometric and ELISA studies were performed strictly according to approved laboratory protocols, ensuring high accuracy and reproducibility of results. These methods are suitable for evaluating metabolic processes associated with osseointegration and bone remodeling.

Statistical analysis
Statistical analysis was carried out with the help of Statistica 12 software (StatSoft). Histogram analysis was used to check the normality of the distribution of quantitative data. For group comparisons, a Student's t-test for independent samples was used. An F-test for homogeneity of variances was performed; if the variances were found to differ, the modified Student's t-test was used. Qualitative variables were tested for association by means of Fisher's exact test. Differences with a p-value less than 0.05 were considered significant.

Results and Discussion

Dynamics of alkaline phosphatase activity in the early postoperative period
Results from our study showed a decrease in the level of surgical intervention in oral fluid, as measured by alkaline phosphatase, after one week. This decrease may indicate a short-term inhibition of osteoblastic enzyme activity, probably due to the postoperative bone repair response rather than an injury in the early operational phases. Such dynamics of the indicator reflect the initial stage of the enzymatic adaptation-inflammatory process in the area of implant placement in osteogenesis and temporary dysfunction. During the 14 days after dental implantation, the level of alkaline phosphatase (ALP) activity in the oral fluid remained at the level recorded on day 7, demonstrating relative stability without significant fluctuations. Such dynamics indicate an acute end to the inflammatory phase that occurs in response to surgical intervention and progress to the next stage, the runner of osseointegration, characterized by the non-activation of processes of bone

tissue repair and remodeling [8-15].

A similar trend was observed in subsequent follow-up periods: on the 21st day after implantation, ALP activity in oral fluid remained at a comparable level, confirming the stabilization of biochemical parameters. These data may indicate a favorable course of reparative processes in the upper peri-implant zone, as well as the formation of conditions that promote successful non-osseointegration with the surrounding bone tissue. After dental implantation, patients showed a slight increase in alkaline phosphatase (ALP) activity in oral fluid at 3 days, which probably reflects activation of bone remodeling processes at the implant site. The data obtained during the study allow us to conclude that, in the study groups, during the period of alkaline phosphatase activity in the oral fluid after dental implantation, dynamics reflecting biochemical processes associated with osteointegration and bone remodeling were observed [16-21].

The indicators of enzymatic activity over the next three months, until the end, remained stable, with no fluctuations. Maintaining a stable set of oral hygiene measures is largely due to patients' rational compliance with the recommended value, which contributed to stabilization and provided favorable conditions for the prevention of inflammatory complications of peri-implant tissues. Six months after dental implantation, the level of alkaline phosphatase (ALP) in oral fluid showed a tendency to decrease compared to previous values, approaching the observation level, and no pronounced period was observed in the control group that underwent surgery throughout. These dynamics may indicate functional enzymatic activity in bone tissue at the end of implant adaptation, the formation of a stable osseointegration connection, and the restoration of metabolic balance in the peri-implant zone. Also, such a transition to the clinical state of the early healing phases and the reflection of sustained changes in completion are successful and stable, largely due to postoperative and hygienic recommendations that promote compliance with I Care Complex interests and attract many [22-26].

Quantitative results of ALP and TRKF activity

Table 1. Study period: Indicators of alkaline phosphatase and TRKF in various oral fluids.

No.	A follow-up period	In oral ALP fluid (U/L)	In oral TRKF fluid (U/L)
1	Implantation Up	Upto 26.0 ± 1.2	150.0 ± 10.0
2	7 days	25.2 ± 1.1	Fertilizers were 340.0 ± 25.0*
3	14 days	25.0 ± 1.0	450.0 ± 30.0*
4	21 days	25.5 ± 1.1	400.0 ± 20.0*
5	3rd day of the month	26.5 ± 1.3	200.0 ± 15.0
6	6th day of the month	25.0 ± 1.0	124.0 ± 10.0£

Note. An asterisk (*) indicates significant differences in comparison with the statistical level of the initial one (P < 0.01).
Sign (£) – compared to the group, there is no significant difference (P < 0.05). Data – mean ± standard deviation.

Table 1 presents data on the activity of the enzymatic markers of two dynamic alkaline phosphatases (ALP) and tartrate-resistant acid phosphatase (TRAP) in oral fluid from patients after dental implantation at different follow-up periods. Alkaline Phosphatase (ALP): Before implantation, the average level of alkaline phosphatase in benomyl is 26.0 ± 1.2 U/l, which is taken as the initial background. On days 7, 14, and 21 after implantation, the enzyme level decreased slightly (25.0-25.5 U/L); however, the statistically significant changes persisted through the end. After 3 days of the month, there was a slight increase in ALP activity to 26.5 ± 1.3 U/L, probably reflecting the activation of bone remodeling processes. After 6 months, the enzyme level decreased again to 25.0 ± 1.0 U/L, indicating the completion of adaptation and the stabilization of functional osseointegration. No significant fluctuations were observed compared with the level of go [27-31].

Dynamics of tartrate-resistant acid phosphatase (TRKF) in the early period
Before dental implantation, patients had higher beta-tartrate-acid-resistant phosphatase (TRAP) activity than the control groups (40.5%). This indicator may indicate pronounced osteoclastic bone resorption and increased physical activity, which should be taken into account during metabolism before bone marrow implantation in the evaluation state, as shown in **Figure 1**.

On the 7th day after dental implantation, patients showed a significant 2.3-fold increase in beta-acid-resistant phosphatase (TRKF) activity compared to the initial parameters. Furthermore, the increased level of enzymatic activity was maintained on the 14th and 21st days after surgery, with a peak in competence on the 14th day, when TRKF activity was 3 times the initial level. During the follow-up period, a gradual decrease in TRKF activity was observed, as shown in the quantitative results. The average level of TRKF implantation in benomyl is up to 150.0 ± 10.0 U/l. On days 7, 14, and 21, researchers observed a statistically significant change from baseline (P < 0.01) [32].

Medium-term dynamics of TRKF (3 and 6 months)
Medium-term dynamics of the TRKF (3 and 6 months). On the 3rd day of the month after implantation, the average level of tartrate-resistant acid phosphatase (TRKF) mica benomil was 200.0 ± 15.0 U/l. TRKF level decreased at 6 months to 124.0 ± 10.0 U/L.
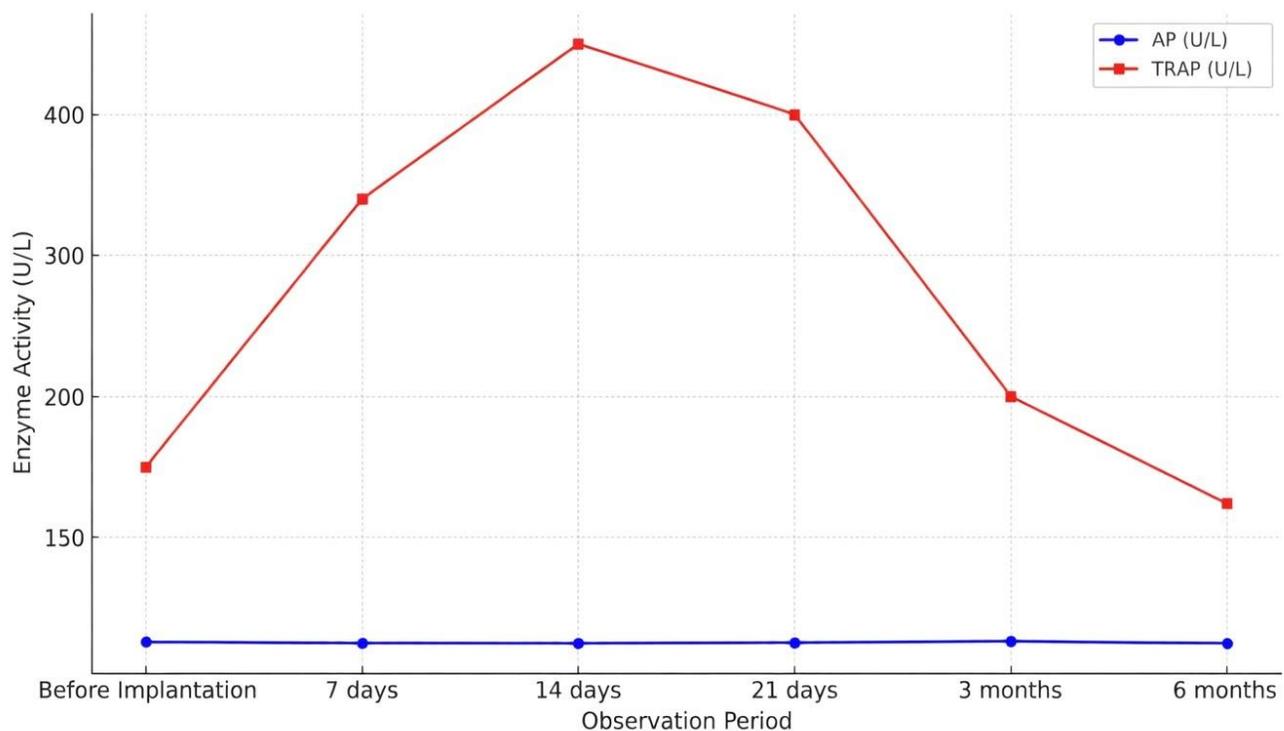
Figure 1. Dynamics of ALP and TRKF activity and oral fluid after dental implantation.

Interpretation of alkaline phosphatase dynamics

Alkaline phosphatase (ALP) is a well-established marker of osteoblastic activity and bone mineralization, playing a central role in bone formation and metabolic regulation. In the present study, the observed slight decrease in ALP activity during the first week after dental implantation may reflect a transient suppression of osteoblastic function associated with surgical trauma and the early inflammatory response. Also, findings by Vimalraj *et al*. indicate that it is consistent with the physiological sequence of bone healing, in which inflammatory and resorptive processes precede active osteogenesis [33]. The stability of ALP levels during the second and third postoperative weeks suggests resolution of acute inflammation and transition to early osseointegration without excessive metabolic disturbance, as shown in the study by Rakholiya *et al*. [34]. The moderate increase in ALP activity observed at three months likely reflects activation of bone remodeling and osteoblastic differentiation, indicating progression toward secondary stability of the implant [35]. The subsequent decrease in ALP activity over 6 months, approaching baseline values, reflects normalization of bone metabolism and the completion of adaptive remodeling processes. Overall, minimal fluctuations in ALP activity throughout the follow-up period support a favorable, controlled osseointegration process without pathological inflammation or excessive bone turnover.

Interpretation of tartrate-resistant acid phosphatase (TRAP-5b) dynamics

Tartrate-resistant acid phosphatase (TRAP-5b) is a specific marker of osteoclastic activity and bone resorption. The elevated baseline TRAP-5b levels observed before implantation suggest pre-existing bone turnover activation, which may be influenced by functional loading, age-related remodeling, or subclinical inflammatory conditions [36]. The pronounced increase in TRAP-5b activity during the first two weeks after implantation reflects the expected osteoclastic response to surgical trauma and inflammatory signaling in the peri-implant bone. The peak TRAP-5b activity recorded on day 14 indicates maximal resorptive activity, which is biologically necessary for the removal of damaged bone tissue and preparation of the bone surface for subsequent new bone formation [36]. The gradual decline in TRAP-5b levels after day 21 and during the medium-term follow-up suggests attenuation of inflammatory and resorptive processes. By six months, TRAP-5b activity decreased below baseline and control values, indicating suppression of osteoclastic activity, stabilization of bone tissue, and successful transition from active remodeling to functional osseointegration.

Balance between resorption and formation during osseointegration

The combined assessment of ALP and TRAP-5b provides valuable insight into the balance between bone resorption and formation following dental implantation. The early postoperative period is characterized by dominant osteoclastic activity, as reflected by elevated TRAP-5b levels, while osteoblastic activity remains relatively stable. This imbalance gradually shifts as resorptive activity decreases and osteogenic processes become predominant, leading to structural stabilization and integration of the implant into the surrounding bone [37]. The observed

temporal sequence confirms the physiological phasing of bone remodeling, progressing from inflammation and resorption to repair, maturation, and homeostasis. The absence of prolonged elevation of resorptive markers or excessive suppression of osteogenic markers suggests an uncomplicated healing course and effective biological adaptation of peri-implant tissues, as also shown by Qin *et al.* [38].

Clinical implications of enzymatic monitoring
Monitoring ALP and TRAP-5b activity in oral fluid provides a non-invasive means of assessing peri-implant bone metabolism. TRAP-5b appears particularly sensitive to early inflammatory and resorptive changes, making it a valuable marker for identifying patients at risk of delayed healing or peri-implant complications. In contrast, ALP reflects longer-term osteogenic stability and may serve as an indicator of successful bone formation and implant integration [39]. The characteristic "increase–peak–decrease" pattern of TRAP-5b during the early postoperative period may help guide clinical decision-making, particularly regarding timing of functional loading and intensity of postoperative care. Normalization of enzymatic activity over 3 to 6 months supports the feasibility of progressive loading strategies in patients with favorable biochemical profiles [40].

Future recommendations
Extended follow-up studies
Future research should include longer observation periods beyond six months to evaluate the long-term stability of enzymatic markers and their association with implant survival and peri-implant bone loss [41].

Inclusion of additional biomarkers
The combined analysis of ALP and TRAP-5b should be supplemented with other bone metabolism markers, such as osteocalcin, P1NP, or inflammatory cytokines, to provide a more comprehensive assessment of peri-implant remodeling [42].

Standardization of sampling protocols
Further studies should strictly standardize preanalytical conditions for oral fluid collection, including time of day, fasting status, oral hygiene measures, and exclusion of confounding factors such as smoking or physical exertion [43].

Correlation with clinical and radiological outcomes
Biochemical data should be correlated with clinical parameters, resonance frequency analysis (ISQ), probing depth, bleeding indices, and radiographic bone changes to validate the diagnostic and prognostic value of enzymatic markers [43].

Personalized implant loading strategies
Future investigations should explore the use of ALP and TRAP-5b dynamics to individualize implant loading protocols and postoperative management, particularly in patients with systemic risk factors or compromised bone quality [44].

Conclusion

The results of this study demonstrate the clinical relevance of enzymatic markers in assessing peri-implant bone metabolism and identifying potential disturbances of osseointegration in the postoperative period. Analysis of alkaline phosphatase (ALP) activity revealed no statistically significant changes throughout the observation period, which may indicate weakly expressed or unstable osteoblastic activity during the early and intermediate stages after dental implantation. In contrast, tartrate-resistant acid phosphatase (TRAP-5b), reflecting osteoclastic activity, showed a pronounced, statistically significant increase, exceeding baseline values by more than 3-fold in the early postoperative period. Elevated TRAP-5b levels persisted during subsequent follow-up, including the six-month observation point, indicating an active inflammatory and resorptive response in the peri-implant bone tissue. These changes correspond to the physiological phase of bone remodeling, in which resorption precedes new bone formation and structural reorganization. A gradual decrease in TRAP-5b activity over time, accompanied by stabilization of bone metabolism markers, reflects a transition from the active inflammatory-resorptive phase to a more mature remodeling stage and the completion of osseointegration. Overall, the observed enzymatic dynamics confirm the feasibility of using ALP and TRAP-5b as informative, non-invasive biomarkers for monitoring bone remodeling processes and evaluating the biological course of osseointegration following dental implantation.

Ethics statement: The study protocol was reviewed and approved by the Ethical Committee of Osh State University (Osh State University). All research procedures were conducted in accordance with the ethical principles outlined in the Declaration of Helsinki (Declaration of Helsinki).

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