Cone Beam Computed Tomography Value in Diagnostics of Scaphoid Bone Injury Complications

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**Aims and objectives**

High functional significance of the hand in a human's life determines a great importance of its injuries diagnostic and treatment. Wrist damages represent approximately 49% of all musculoskeletal system injuries, constitute from 25 to 35% among all hand injuries and determine about 13% cases of disability [8, 14, 15]. At the same time in patients with wrist fractures the integrity violation of the scaphoid bone is diagnosed most often and according to some researchers ranges in 54-88% of all cases [2, 6, 14-17]. The experts data indicate that about 0.2% of all referrals to emergency departments are patients with scaphoid fracture (SF) [4].

SF detection presents significant difficulties [8]. Late diagnosis and subsequent inadequate treatment, often associated with short-term immobilization, lead to different complications: false joints in 4-25% patients, aseptic necrosis of proximal fragment occurring in 35-48% cases. SF complications are certainly due to anatomical and physiological characteristics of scaphoid bone. Along with this, it is worth noting that late SF diagnosis is often connected with difficulties of X-ray examination data interpreting [14, 15].

Standard radiography (SR) is the most commonly used technique for the diagnosis of SF, but has a low sensitivity and a high percentage of false-positive results both in acute injury and control studies. The sensitivity of radiography in the SF detection is about 70%. The number of cases with a bright clinical implication and the lack of a fracture on the X-ray does not exceed 3% during the first 24 hours [2-5]. In order to diagnose suspected SF and its complications, and for treatment results monitoring polypositional X-ray examination is recommended: anteroposterior and lateral projections, two mutually perpendicular oblique views (at the angle of 45°) and anteroposterior projection with a deviation of the hand in the ulnar direction (view of the scaphoid bone) [3, 13-15, 20].

Computed tomography (CT) is typically used to identify fractures and non-unions for preoperative planning, and is advantageous in the detection of incomplete fracture sensitivity 94% and specificity of 96% [16, 21]. In their studies J. M. Ty et al. (2008) found that in 99% cases MSCT reveals fractures [19].

Nowadays, as a result of the development of up-to-date special-purpose cone-beam computed units, it became possible to examine wrist. Cone-beam computed tomography (CBCT) imaging is based on scanning the region of interest with usage of a pulsed X-ray beam. It is collimated so that the radiation is structured in the form of a cone. The tissue-attenuated X-ray radiation, then reaches a flat-panel detector. The use of cone-beam technology means that a single turn of the X-ray tube around the target generates a primary image ready for further post-processing. Another important advantage of CBCT vs MSCT is the potential for a significant reduction in exposure dose, due to the short duration of direct X-ray irradiation and high sensitivity of the flat-panel detector. Recent numerous studies have demonstrated that CBCT of wrist with its high spatial resolution
and wide spectrum of images post-processing has a high accuracy, sensitivity and specificity in the detection of pathological bone structure remodeling. This effect remains even in cases when its size do not exceed 1-2 mm. These capabilities and advantages mean that CBCT provides an expedient alternative to MSCT for the examination of wrist and hand injuries [1, 7, 9-12, 18].

The actual literature indicates absence of publications on applicability of CBCT SF and its complications. The role and place of CBCT in the diagnostic algorithm in such patients has not been specified yet. All these factors have become the basis for performing this study.

Before performing the study the following aims and objectives were formulated:

- to indicate the hand and wrist CBCT opportunities of the main X-ray signs identification of the SF and its complications;
- to determine the capabilities of CBCT in the diagnosis of complicated fractures of the scaphoid bone compared to the SR;
- to clarify the role and place of the hand and wrist CBCT in the diagnostic algorithm in patients with SF and its complications.
Methods and materials

The group of 137 patients: 46 women and 91 men at the age from 21 to 48 with determined diagnosis acute SF presenting less than 6 weeks from initial injury in anamnesis was formed. The preliminary diagnosis was exhibited on the basis of standard X-ray (posterior-anterior, lateral, oblique - semipronated, oblique - semisupinated projections). In addition, it was found that 81 of them had different kinds of complications: non-union or delayed union, displacement (translation and / or humpback deformity) and comminution.

Herbert and Fisher defined SF as stable and unstable, as well as having delayed union and nonunion. Type A fractures are stable acute fractures, and type B fractures are unstable acute fractures. Although type A fractures can potentially be treated nonoperatively, other types of fractures usually require surgical treatment. Type A fractures include tubercle fractures (A1) and incomplete waist fractures (A2). Type B fractures include distal oblique fractures (B1), complete waist fractures (B2), proximal pole fractures (B3), transscaphoid perilunate dislocation fractures (B4), and comminuted fractures (B5). Type C fractures are delayed unions, and type D fractures are established nonunions, either fibrous (D1) or sclerotic (D2). Based on this classification, other than tubercle and incomplete waist fractures, all other types are considered unstable [16]. According to Herbert's classification all the patients were divided into four groups.

In all the groups of patients CBCT of wrists was performed for dynamic control implementation. Before scanning each patient signed a voluntary informed consent to participate in the X-ray study using CBCT.

CBCT of the wrists was carried out using a specialized cone-beam computed unit (NewTom 5G, QR s.r.l., Italy). It has the following technical characteristics: 200 × 250 mm flat-panel detector size, 180 × 160 mm maximum field of view, and a 360° gantry rotation around the region of interest (Fig. 1). All the examinations were conducted from the forearm bones distal metaphysis to the distal ends of the metacarpal bones. Settings were the following: scan mode - «patient scan» (exposure time - 3.6 s, X-ray tube boosting voltage - 110 kV, current - 0.6-0.8 mA), scan type - «regular scan», scan time - 18 s (Fig. 2). The CBCT wrist examinations were performed in special-purpose positioning setups allowing full coverage of the interest area.

All the received images were evaluated by two experienced readers, assessing its quality and all the wrist bones and joints pathological findings. The obtained data have been compared with the SR results.

In addition calculations of direct costs of different ray methods of the hand and wrist examinations have been performed and analyzed. The received results were compared also.
### The Unit Technical Characteristics

<table>
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<th>Flat Panel Detector Size</th>
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<tr>
<td>Focal Spot Size</td>
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<tr>
<td>Voxel Size</td>
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**Fig. 1:** The CBCT-Unit Technical Characteristics

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### Scanning parameters

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<table>
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<tr>
<td>Current</td>
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**Fig. 2:** CBCT Scanning Parameters

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Results

It was found a significant difference in detection of joints and bones changes, healing complications and treatment outcomes of SF between CBCT and SR data (Fig. 3).

The received CBCT-images were characterized by the detailed mapping of the bone structure with the accurate bone structure differentiation. Small bone fragments and areas of pathological alteration of bone tissue (even under 1-2 mm) were observed reliably on the CBCT-tomograms. When scanning the patients with metal constructions (for example, spoke or screw) or high density materials, our attention was attracted also by the lack of significant artifacts from it on the CBCT-images (Fig. 4).

X-ray signs of the following complications were visualised reliably: avascular necrosis, osteoarthrosis, ankylosis, some kind of inflammatory process, delayed consolidation, false joint. CBCT-images were distinguished by high spatial resolution, optimal signal-to-noise ratio, uniform accuracy and dynamic range grayscale, which allowed estimating not only of bone structure, but dense soft tissue formations as well: muscles, ligaments and tendons.

According to Herbert's classification all the patients were divided into four groups (Fig. 5):

1. Delayed consolidation - n = 21 (25.9 %);
2. Pseudarthritis - early deformity - n = 32 (39.5 %);
3. Sclerotic pseudarthrosis - advanced deformity - n = 63 (77.8 %) with ankylosis at 4 patients (4.9 %);
4. Avascular necrosis and pseudarthrosis (Fig. 6) - fragmental proximal pole - n = 29 (35.8 %).

Additionally, in 16 patients (19.8 %) inflammatory process was observed.

By the time passed since the trauma, in 63 patients (77.7 %) were found signs of false joint. In 22.2 % of cases it was represented with a pronounced sclerosis in the fracture zone, diastasis, cystic and sclerotic bone restructuring (Fig. 7), but it is worth noting that CBCT-sections study in various planes has enabled us to identify the main zone of pathological changes that were taken into account when planning surgical intervention and bone grafting technique.

In 65 cases (80.2 %) - non-union fractures (Fig. 8). In one patient a chronic SF was the consequence of the transferred fracture-dislocation of the hand simultaneously eliminated by a closed manual reposition.
The majority of injured showed signs of instability of the fracture, which resulted in varying degrees of displacement of the fragments. In 9.9% of cases fragments displacement were not observed on X-ray film, but always visualized reliably with CBCT during data post-processing.

54.3% among such patients had multiplanar displacement of the scaphoid bone fragments. Most often dislocation of scaphoid distal fragment in the sagittal plane toward the palm together with the inside rotation was determined. In turn, the proximal fragment was additionally deployed together with the lunate bone slightly more to the rear and outward. In the end, the displacement of the fragments was accompanied by the formation of the angular deformation of the navicular bone with the angle between atomtime open in the palmar direction.

And one case was identified improperly healed transverse SF in the middle third with angular displacement, tilt, lunate bone at an angle of 20° to the rear and dorsal subluxation of the capitate bone capitate in-moon-junction, which further demanded the implementation of corrective osteotomy of the navicular bone. Also, in one case, the fracture in the process of CBCT was revealed a small, loose bone fragment of about 4 mm is not visualized on plain radiographs that were taken into account in the choice of surgical access.

Also we analyzed the X-ray dose data for patients during the studies which showed that the indicators for CBCT and SR are comparable (Fig. 9).

As a result of calculation and comparison of the direct costs for wrists and hands different ray researches (Tab. 1) it was found that its results were comparable for SR and CBCT. In addition, the implementation of CBCT is approximately 3.6 times cheaper than MSCT of this anatomical segment and MRI - in 7.2 times.
Fig. 3: CBCT-images of the left wrist with SF. Aftertreatment control.

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Fig. 4: CBCT-images of wrists with the detailed mapping of the bone structure with the accurate bone structure differentiation. Small bone fragments and areas of pathological alteration of bone tissue are observed reliably. The lack of significant artifacts from metal constructions.

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Fig. 5: Groups of Patients

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Fig. 6: CBCT-images of the right wrist with the signs of avascular necrosis. 5 months after injury.

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Fig. 7: CBCT-images of the left wrist. Signs of false joint: a pronounced sclerosis in the fracture zone, diastasis, cystic and sclerotic bone restructuring. 6 months after injury.

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**Fig. 8:** CBCT-images of the right wrist with the signs of non-union SF. 8 months after injury

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**Fig. 9:** X-ray Dose Comparison

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<tr>
<td>CBCT</td>
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<td>MSCT</td>
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<tr>
<td>MRI</td>
<td>106.8</td>
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</table>
Table 1: Direct Cost Indicators for Ray Researches of Hand and Wrist

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Conclusion

The most significant were CBCT benefits in cases of small (< 1-2 mm) bone pathological alteration visualization especially in the presence of metal and boneplastic material. Taking into account also low radiation dose, high spatial resolution, and relatively low direct cost of the study, CBCT could be considered as the main diagnostic method for the SF and its complications diagnosis. Additionally, this technique could be used in dynamics, while monitoring treatment effectiveness, replacing gradually SR.
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References


