Review article
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Reconstruction of finger function in case of joint defects

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Abstract

Introduction Repair of bone defects in the hand is still a challenge despite advancements in hand surgery and improved surgical techniques. However, the main difficulty still lies in restoring the function of the injured segment when the defect affects functionally significant joints including the proximal interphalangeal and metacarpophalangeal joints of the fingers. Loss of mobility in the joints significantly impairs the physical capabilities of patients and the quality of life. A reconstructive intervention is primarily aimed at restoration of the useful range of motion of the involved finger with minimal risks of postoperative complications.

The **objective** was to evaluate the possibilities with finger function restoration and the effectiveness of the techniques used to repair defects in the fingers joints based on literature analysis.

Material and methods The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru) and the National Library of Medicine (www.pubmed.org), Elseiver, Google Scholar (2008 to 2024) and using keywords: finger joint defects, bone loss, intra-articular injuries of the fingers, arthroplasty, small joint replacement, reconstruction of finger joints, joint restoration, metacarpophalangeal joint, proximal interphalangeal joint, bone graft, joint transplantation, joint transfer, microsurgery, vascular bone joint transfer. Sixty articles by foreign authors and 11 publications of Russian researchers were selected for analysis.

Results and discussion With the variety of surgical techniques, there is no universal method for replacing defects in the finger joints. Along with the high rate of postoperative complications, the lack of an optimal method requires careful preoperative planning. Reconstructive interventions should be considered as a method of choice and an alternative to arthrodesis in young, physically active patients. Limited postoperative range of motion in the reconstructed joint is a challenge in the treatment of patients with this pathology. The choice of surgical strategy relies on the patient's compliance for a complex and lengthy rehabilitation in achievement of a functionally satisfying result.

Conclusion Reconstructive interventions for repair of a bone defect in the joint are practical for increasing the useful range of motion of the involved finger and improving the physical capabilities of the hand.

Keywords: finger joint defects, bone defect, intra-articular injuries of the fingers, arthroplasty, small joint replacement, finger joint reconstruction, joint restoration, metacarpophalangeal joint, proximal interphalangeal joint, bone graft, joint transplant

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INTRODUCTION

Bone defects in the hand are a common problem that significantly reduces the functionality of patients and impairs the quality of life. Trauma, infections or tumor are three main causes of bone defects [1]. The cause of the defect, the choice of surgical technique is largely determined by its location and size, and concomitant injury to neurovascular structures, tendons and/or soft tissue defects [1, 2].

The metacarpophalangeal and proximal interphalangeal joints play a decisive role in the hand functioning, providing the basic range of motion of the fingers and the ability to accurately position them for fine motor skills [3]. Bone defects are often observed in young active patients with high functional demands. Restoration and preservation of the optimal range of motion in the joints is one of the goals of a reconstruction in case of a complex injury [4, 5]. The surgical treatment is aimed at anatomical repair of the defect and increase of the functional range of motion of the finger to facilitate everyday use [1].

With the variety of methods used to repair bone defects as an emergency or a selective procedure and variations in the implementation they are associated with a high risk of postoperative complications and have a number of contraindications [2, 6]. The choice of a reconstruction method for the finger joints remains a challenge with no evident clear solution identified [3]. The lack of a "gold standard" in the treatment of patients with the condition and high frequency of its occurrence mainly in the working population, determines the significance of the problem of treating patients with defects of the metacarpophalangeal and proximal interphalangeal joints of the fingers.

The **objective** was to evaluate the possibilities with finger function restoration and the effectiveness of the techniques used to repair defects in the finger joints based on literature analysis.

MATERIAL AND METHODS

The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru) and the National Library of Medicine (www.pubmed.org), Elseiver, Google Scholar (2008 to 2024) and using keywords: finger joint defects, bone loss, intra-articular injuries of the fingers, arthroplasty, small joint replacement, reconstruction of finger joints, joint restoration, metacarpophalangeal joint, proximal interphalangeal joint, bone graft, joint transplantation, joint transfer, microsurgery, vascular bone joint transfer. Sixty articles by foreign authors and 11 publications of Russian researchers were selected for analysis.

RESULTS AND DISCUSSION

Useful range of motion of the fingers

Loss of normal movement in the fingers and decreased functionality of the hand can be extremely distressing for the patient. According to various authors, the active range of motion (amplitude of full flexion) is 0–100° (mean 84°) in the metacarpophalangeal joints (MCP), 0–105° (mean 105°) in the proximal interphalangeal (IPJ) joints, 0–85° (mean 69°) in the distal interphalangeal joints (DIPJ) [7, 8]. The full amplitude of finger flexion is not required for everyday physical activities with the functional range being sufficient measuring 19–71° (mean 61°) for the MCP joint, 23–87°

(mean 60 °) within for the PIP joint and 10–64° (mean 39°) for DIPJ [8, 9]. Therefore, different surgical treatments is mainly aimed at achieving a functional range of motion in the injured finger to improve the patient's quality of life.

Types of surgical treatments

The choice of surgical strategy relies on the location and size of the defect. The patient's age and level of daily activity, compliance with the intended treatment plan are the key factors influencing decision-making [10, 11, 12, 13]. The operation can be aimed at eliminating movement in the injured joint (arthrodesis) or restoring the function through reconstructive surgery. If reconstructive surgery cannot be performed or there are contraindications to reconstruction, arthrodesis is the method of choice with a primary downside being the loss of joint mobility [2, 11, 14]. With significant soft tissue damage, tendon and nerve defects, shortening and joint fusion in a functional position may be a better choice is distinguished from the need for repeated surgical interventions, which may be the best solution for the patient who wants to reduce the recovery time and resume other activities [15]. Like any surgical intervention, joint fusion can be associated with a risk of postoperative complications including peri-implant infection and postoperative pain; the non-union (failed arthrodesis) rate is reported in 3.9–8.6 % of cases [16]. Although the end result of pain-free stability provided by arthrodesis may be acceptable to the patient, maintaining mobility in a functionally significant joint remains the primary goal of surgical treatment [13].

Interpositional arthroplasty [17, 18], arthroplasty using a free osteochondral autograft [14, 19, 20, 21, 22, 23] or allograft [2], arthroplasty with blood-supplied bone transplant [12, 24] can be used to replace a bone defect, reconstruct the articular surfaces forming the MCP joint or PIP joint, and restore mobility in the joints. Vascularized or non-vascularized joints from the foot [4, 6, 10, 25, 26], toe [27] or joint replacement can be employed for reconstruction of the MCP or PIP joint [28, 29].

Interpositional arthroplasty suggests resection of the involved portion of the joint and grafting between the articular surfaces to regain some mobility and relative stability of the joint. Fascia, tendon, allograft or synthetic material can be used as a graft. Early mobilization of the joint can be initiated with sufficient graft fixation to achieve a satisfactory range of motion. However, this technique does not help to repair the bone defect of the articular surface, and graft survival is rather short. Over time, it transforms into scar tissue and loses its sliding characteristics leading to persistent contractures in the involved joint [17, 18, 30, 31].

Osteochondral autografts are commonly used for reconstructions. The bases of the metacarpals [24], the distal femur [12], the proximal tibia [32], the foot joints [4] or potentially the toe [27], and rib fragments [19, 20] can be used as donors for the restoration of the articular surface.

The plastic surgery with a blood-supplied non-free osteochondral graft is associated with the lower risk of resorption and infection. However, the limited size of the graft and the length of the vascular pedicle reduces indications for reconstruction of larger bone defects using the method [13, 24]. Hemi-hamate arthroplasty can be used to replace bone defects in the articular surface of the base of the middle phalanx in treatment of fracture-dislocations in the PIPJ (sometimes in combination with volar plate plastic surgery to provide greater stability in the joint) [33, 34]. The technique is impractical in cases of absent articular surface; it is associated with the risk of dislocation in the reconstructed joint due to the difficulty of simultaneous restoration of the capsular-ligamentous apparatus, graft resorption and progression of deforming arthrosis reported in 16 % [34]. Osteochondral grafts from the femoral

condyle are used for post-traumatic defects of the cartilage [35, 36] but there are examples of its use for larger bone defects [12]. The technique has limitations due to the size of the graft and difficulties in shaping the graft to fit the articular surface defect. Pain at the donor site that would require therapy and correction of physical activity is a common postoperative complication [35].

The advantages of a rib graft include the possibility of reconstructing a damaged joint without affecting other (healthy) joints and giving the graft any shape comparable to the size of the defect, with minimal risk for the donor site. This reconstruction option has age restrictions (not recommended for patients aged 60 years and older due to ossification of the cartilage), the graft is at risk of a fracture, cartilage degeneration and narrowing of the joint space. The technique can be associated with additional interventions for reconstruction of the capsular-ligamentous apparatus, tenolysis, corrective osteotomy at the graft site or removal of metal constructs reported in 40 % [19].

The choice of a donor site is essential for repair of the joint or a large intra-articular defect. Hand grafts are technically accessible and anatomically suitable. The transplants can be used for reconstruction of several injured fingers with high level of trauma to the donor area and with one to be used as a donor graft [26, 27, 37, 38].

Extensive metacarpophalangeal defects can be repaired with combined use of bone grafts to address metacarpal defect and restore joint mobility with a silicone implant [39, 40]. The authors reported the free vascularized fibula graft as an ideal option for metacarpal bone defects with the harvesting being less complicated compared to other free vascularized grafts [39].

Allografts have good osteoconductive properties and can be used for reconstruction in cases where other techniques are difficult to perform or are contraindicated [2]. Although their use is not associated with trauma to healthy tissue, they are less resistant to infection and are more often subject to rejection or progressive resorption with the risk of fractures/nonunion, which may subsequently require joint replacement [41]. Repair of the defect with an allograft would require preserved ligaments to achieve stability in the joint, which is not always feasible in the case of a complex injury to the finger [6].

Joint replacement is often the method of choice for the treatment of post-traumatic or other types of arthrosis of the DIPJ and MCP in older patients. This method can be used for acute intra-articular injuries in the cases, when a traumatic defect of the phalanx or the metacarpal is equivalent to joint resection and is an indication for implantation [29, 42, 43, 44]. Nonunited intra-articular fractures of the phalanges of the fingers can be treated with joint replacement [45]. With the variety of small joint implant, none of them has an unconditional advantage in case of bone deficiency, defects of the capsular-ligamentous apparatus [46] or in the presence of post-burn contractures [47, 48]. Despite improvements in modern prostheses and surgical techniques, components may be difficult to stabilize. There is a high risk of infection, a significantly reduced range of motion in the operated finger and the development of peri-implant fractures in 22–35 % with 5–7-year survival prior to revision [28, 49, 50, 51, 52, 53]. The range of motion in the joint fails to reach the functional level after joint replacement [54] and repeated interventions including tenolysis, arthrolysis, tenodesis, plastic surgery of the capsular ligament apparatus may be required in about 58 % of cases to improve mobility and endoprosthetic components would be replaced in cases with progressive instability [50, 55, 56, 57]. Arthrodesis can be performed during revision operations in case of severe

deformity, bone defect and ligamentous failure that cannot be corrected with an implant [55, 58, 59]. Although the role of limited functional loads and extreme positions in the operated joint [60] is essential to predict the risks of postoperative complications including peri-implant fractures and destruction of endoprosthetic components, these data require additional research.

Transplantation of a vascularized or non-vascularized toe joint can be produced in cases where joint replacement is contraindicated or cannot be performed, and the use of another technique would not satisfy the final goal of the surgical intervention [10].

The main indications include joint destruction in younger adults with high functional demands on finger movements [14, 61], in children [62], and in the presence of extensive complex soft tissue injuries [63].

The advantages of the intervention include the comparability of the bone anatomy of the donor and recipient joints, good blood supply to facilitate better fusion, and the possibility of transplanting a joint together with tendons, nerves and skin to compensate for the deficiency in the recipient site. Repair of the donor defect with a resected damaged toe joint minimizes the impact of surgical intervention on the appearance and functionality of the donor foot [5]. Advantages with a foot joint include long graft survival, resistance to resorption and infection, and stability due to transfer with an intact ligamentous complex.

In addition to age restrictions (patients aged 18–25 years reported in various studies) and a formidable list of contraindications (peripheral vascular diseases, previous trauma to the donor site, taking immunosuppressants, smoking, autoimmune diseases, etc.), the technique has some disadvantages including technical difficulties, traumatic impact on the donor site and difficulties in the rehabilitation [6, 64]. The low functional range of motion expected after surgery is the main disadvantage of the method, which is associated with anatomical differences in the structure of the extensor apparatus and an initially smaller range of motion in the toes. Various methods are used to correct anatomical differences, including rotation of the donor joint during placement or performing an oblique osteotomy of the metatarsal head [65, 66]. With all the attempts to improve the technique of grafting a blood-supplied joint, a significant deficit in extension in the reconstructed joint still remains the main problem. According to a 2021 systematic review, the mean range of motion in the PIPJ averaged to (40.3 ± 12.9)° after toe joint grafting with an extension deficit of approximately 30° [61]. The comparison of functional results after transplantation of the blood-supplied joint of the foot and replacement of the involved joint showed it was noted that the range of motion measured (37 ± 9)° and (44 ± 11)° after PIPJ reconstruction and (34 ± 10)° and (47 ± 16)° after MCP reconstruction, respectively. The authors reported the best range of motion in the MCP joint and PIP joint achieved after joint replacement with silicone implants with the rate of complications requiring revision intervention being 18 % compared to 33 % of revisions after joint replacement using a pyrocarbon implant and 29 % after joint transplantation from the foot. The authors concluded that additional research was needed to compare and evaluate the effectiveness of joint replacement using silicone implants and toe joint transplantation in order to determine the optimal type of intervention [67]. According to various authors complications (thrombosis of anastomoses, degenerative changes in the joint, nonunion/union with deformity, fractures, contractures, pain at the donor site) requiring repeated surgical interventions range from 22 to 50 % of cases after transplantation of toe joints

from the foot [26, 61]. Along with the high percentage of postoperative complications, poor clinical results are cause by continued improvement of surgical techniques to improve the functionality and appearance of the reconstructed finger, and reduce trauma to the donor site [25, 68, 69, 70, 71].

CONCLUSION

The literature analysis showed that replacement of intra-articular defects and restoration of the functional amplitude of finger movements remains a challenge in modern hand surgery. There are many surgical techniques aimed at restoring mobility in a lost joint, from low-traumatic ones (interpositional arthroplasty) to extensive microsurgical interventions (joint transplanted from the foot). Reconstructive interventions can be associated with postoperative complications and specific rehabilitation program, so the choice of technique must be deliberate and individual in each clinical case. If a patients want to regain mobility in the impaired joint a reconstructive procedure a reasonable option is a reasonable option in young, physically active patients. Compliance is essential for the patients who undergo difficult and long-term restorative treatment. There are attempts to improve surgical interventions addressing postoperative range of motion and reducing traumatic impact on donor sites. A great number of contraindications to extensive reconstructive operations are limitations to the applications, and a defect in the capsular-ligamentous apparatus and tendons would prevent total joint replacement. Complications requiring revisions due to significant defects in the bone and stabilizing structures would result in arthrodesis, which can be disappointing for the patient and the physician.

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