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Research Article

Osteochondral autologous transplantation versus autologous matrix-induced chondrogenesis for talus osteochondral lesions; a retrospective comparison

Talus osteokondral lezyonlarında osteokondral otolog transplantasyona karşı otolog matriks kaynaklı kondrogenez; retrospektif karşılaştırma

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Abstract

Aim: This retrospective analysis aimed to evaluate the comparative efficacy of osteochondral autologous transplantation (OAT) versus autologous matrix-induced chondrogenesis (AMIC) in the management of osteochondral lesions of the talus (OLT).

Material and Methods: In this retrospective cohort study, 55 individuals (24 males, 31 females) with an average age of 40.7 ± 12.6 years (range 18-66 years) were included. The study assessed 59 ankles in total due to 4 patients undergoing bilateral procedures at separate intervals. Of these, 22 were treated using AMIC and 37 received OAT. Functional outcomes were assessed using the American Orthopaedic Foot and Ankle Society (AOFAS) scale preoperatively and at the latest follow-up. The Lysholm Knee Score was utilized for evaluating knee function in patients subjected to OAT. Serial radiographic examinations of the ankle were conducted to assess osteotomy union, reduction loss, graft subsidence, and progression of osteoarthritis (OA) using the Kellgren-Lawrence grading system for post-treatment OA evaluation.

Results: Comparative analysis revealed no statistically significant differences between AMIC and OAT in terms of improvement in AOFAS scores (p=0.467), progression of OA (p=0.141), or complication rates (p=0.373).

Conclusion: Both AMIC and OAT present as effective therapeutic options for OLT, with comparable success rates and outcomes. Level III.

Keywords: Autologous osteochondral transplantation, Mosaicplasty, autologous matrix-induced chondrogenesis, talus osteochondral lesion, medial malleolar osteotomy

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Öz

Amaç: Bu retrospektif analizin amacı, talus osteokondral lezyonlarının (OLT) tedavisinde osteokondral otolog transplantasyon (OAT) ile otolog matriks kaynaklı kondrogenez (AMIC) tedavilerinin etkinliklerini karşılaştırmalı olarak değerlendirmektir

Gereç ve Yöntemler: Bu retrospektif kohort çalışmasında, ortalama yaşları 40,7 ± 12,6 olan (yaş aralığı 18-66) toplam 55 hasta (24 erkek, 31 kadın) incelenmiştir. Çalışma, dört hastada farklı zamanlarda gerçekleştirilen çift taraflı prosedürler nedeniyle toplam 59 ayak bileğini kapsamaktadır. Hastaların 22'si AMIC, 37'si ise OAT ile tedavi edilmiştir. Fonksiyonel sonuçlar, operasyon öncesi ve son takipte Amerikan Ortopedik Ayak ve Ayak Bileği Derneği (AOFAS) skalası kullanılarak değerlendirilmiştir. OAT uygulanan hastalarda diz fonksiyonunun değerlendirilmesi için Lysholm Diz Skoru kullanılmıştır. Seri radyografik incelemelerle osteotomi hattının kaynama durumu, redüksiyon kaybı, greft çökmesi ve osteoartritin (OA) tedavi sonrası ilerlemesi değerlendirilmiş, OA'nın evrelendirmesinde Kellgren-Lawrence derecelendirme sistemi kullanılmıştır.

Sonuç: Karşılaştırmalı analiz, AMIC ve OAT arasında AOFAS skorlarındaki iyileşme (p=0.467), OA'nın ilerlemesi (p=0.141) veya komplikasyon oranları (p=0.373) açısından istatistiksel olarak anlamlı bir fark olmadığını ortaya koymuştur. AMIC ve OAT, OLT'nin tedavisinde benzer başarı oranları ve sonuçlar ile etkili tedavi seçenekleri olarak karşımıza çıkmaktadır. Düzey III

Anahtar Kelimeler: Otolog osteokondral transplantasyon, Mozaikplasti, otolog matriks kaynaklı kondrogenez, talus osteokondral lezyonu, medial malleol osteotomisi

Introduction

Osteochondral lesions of the talus (OLTs) mainly affect the lateral and medial regions of the talus, with the majority being caused by trauma. According to empirical data, trauma is responsible for 93-98% of lateral lesions and 61-70% of medial lesions.[1-3] Other factors that contribute to their occurrence include avascular necrosis, systemic vasculopathy, chronic microtrauma, as well as endocrine, metabolic, and genetic predispositions. [3,4] Although smaller lesions may not exhibit symptoms, larger ones can cause clinical presentations such as pain, stiffness, and swelling. Advanced imaging techniques have significantly improved the ability to characterize these lesions, providing comprehensive details about their nature and extent. [5]

The decision to administer OLT treatment is typically based on several factors, such as the duration of symptoms, the size, grade, and depth of the lesion, the presence of any concomitant pathologies, and the age of the patient. Asymptomatic lesions may be detected incidentally. Typically, these lesions do not require treatment, but they should be monitored radiologically for evidence of progression. Conservative treatments can be initially applied in the treatment of acute onset, non-displaced, low-grade, and small-sized lesions. Conservative treatment methods frequently include plaster casting, rest, activity modification, and anti-inflammatory medications. Although conservative treatment can be useful, a meta-analysis has shown that its success rate is only about 45%.[6] This approach has limitations, such as a limited ability to return to previous levels of athletic activity and the potential for early onset of ankle osteoarthritic changes. [7] Lesions that do not respond to non-operative treatment for an extended period of 3 to 6 months are then considered for surgical intervention. [8] However, surgical treatment may also be appropriate for displaced, advanced, or large lesions that present with chronic complaints without attempting conservative treatment. [9]

The primary objective of the treatment is to repair the damaged cartilage and subchondral bone with healthy tissues and achieve a pain-free ankle with normal function. Additionally, it aims to prevent the development of ankle osteoarthritis in the long term. Currently, there are several methods for treating talus osteochondral lesions. The most commonly used methods include bone marrow stimulation (microfracture) and retrograde drilling, autologous matrix-induced chondrogenesis (AMIC), autologous chondrocyte implantation (ACI), matrix-induced autologous chondrocyte implantation (MACI), osteochondral autograft transfer (OAT), osteochondral allograft, and particulated juvenile cartilage allograft transplantation (PJCAT) and metallic implants. [8] Traditionally, it is generally believed that arthroscopic bone marrow stimulation techniques should be used as the first line of treatment for lesions under 1cm2. [10] Although it is a minimally invasive technique, the cartilage formed with this method is fibrous cartilage, which can lead

to deteriorating results in the long term. For advanced, large, and deep lesions, it is suggested that advanced regenerative or replacement techniques that might necessitate medial malleolar osteotomy should be used. While each technique has its advantages and limitations, including cost, donor site morbidity, and varying success rates, there are very few comparative studies in the relevant literature. [11]

The current study focuses on comparing two specific surgical techniques: Autologous Matrix-Induced Chondrogenesis (AMIC) and osteochondral autologous transplantation. AMIC combines microfracture surgery with a cell-free scaffold, improving repair tissue quality. Osteochondral autograft transplantation (OAT), or mosaicplasty involves transplanting autologous osteochondral plugs to the defect site. While both techniques are designed to repair articular defects, there is a lack of direct comparative studies between them. This study seeks to address this gap by evaluating the effectiveness of AMIC and OAT in the treatment of OLT lesions.

Material and Methods

Patients and study design

A retrospective review was conducted on patients who underwent either OAT or AMIC procedures for medial-sided OLT between 2015 and 2020 in the authors' institution. Patients with less than 12 months of follow-up, incomplete medical records, and patients under 18 years of age were excluded from the study. During the analyzed period, a total of 55 patients (59 ankles) were evaluated, accounting for four individuals undergoing sequential bilateral procedures. Among these cases, 21 patients (22 ankles) underwent autologous matrix-induced chondrogenesis (AMIC) treatment, and 34 patients (37 ankles) received osteochondral autologous transplantation (OAT). The surgeon made the decision regarding the technique for cartilage restoration during the procedure without applying any randomization process.

All pertinent radiological data, preserved within the Picture Archiving and Communication System (PACS), along with patient charts, comprehensive medical records, detailed operative reports, and notes documented during follow-up, were retrieved from our institution's medical database. These resources were meticulously utilized to collate demographic details, clinical observations, and imaging results pertinent to the study. The study protocol was approved by the institutional review board. (Approval number: 3/15-2023) A written informed consent was obtained from each patient. The study was conducted in accordance with the principles of Helsinki and its subsequent updates.

Surgical Technique

For all cases involving osteochondral lesions of the talus (OLT), access to the talar dome was achieved through a biplanar chevron osteotomy of the medial malleolus. Initial preparation involved the use of two K-wires drilled in parallel. In a subset of thirty-seven ankles, osteochondral autogenous transplantation method (Mosaicplasty, provided by Smith & Nephew, USA) was applied, where the osteochondral grafts were obtained from the edge of the superolateral aspect of the ipsilateral knee's trochlea via a limited arthrotomy (Figure 1). For the remaining twenty-two ankles, a cell-free cartilage implant, specifically the Alpha ChondroShield® made from a polyglycolic acid (PGA) polymer forming an absorbable non-woven textile fleece, was utilized in conjunction with augmented marrow stimulation. This implant serves as a scaffold post-microfracture to facilitate the migration and differentiation of mesenchymal progenitor cells from the subchondral bone (Figure 2). The osteotomy was subsequently reduced and secured with dual parallel compression screws positioned using the pre-established K-wire tracks, while reduction integrity was maintained with towel clamps. Verification of osteotomy and articular congruity was confirmed via final fluoroscopic imaging. Depending on the surgeon's preference, an additional stabilizing screw might be inserted parallel to the joint line in specific cases.

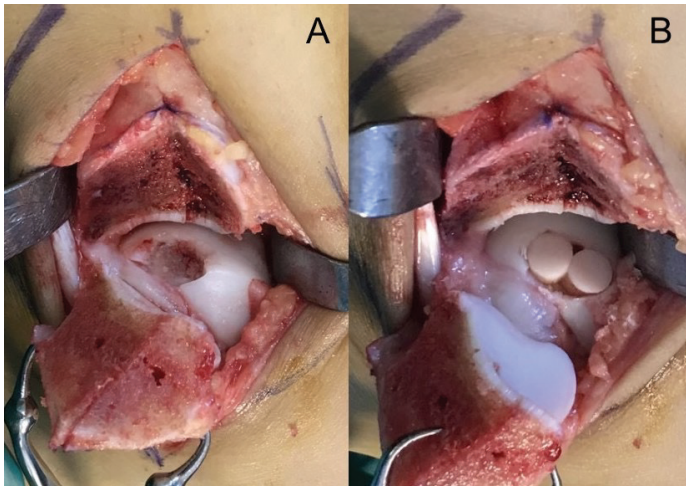

Figure 1. A: Following the medial malleolus osteotomy, the talar lesion was revealed, having been debrided and prepared. **B:** The harvested plugs taken from the knee were appropriately positioned within the lesion

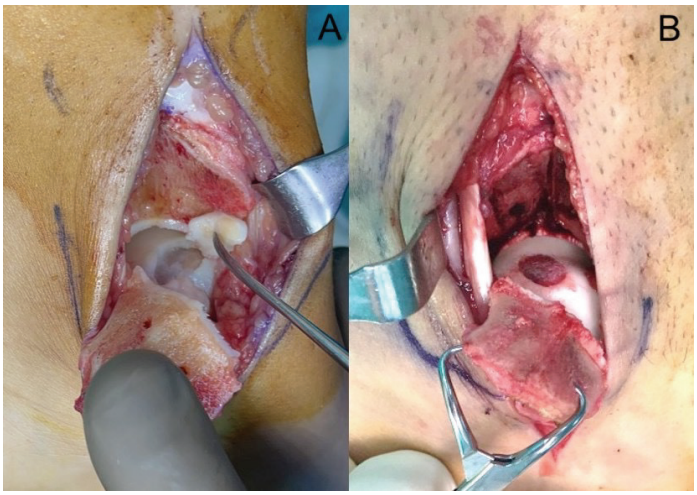

Figure 2. A: The medial malleolus osteotomy exposed a significant chondral lesion along the medial edge of the talus. The osteochondral fragment was precisely separated from the adjacent healthy cartilage **B:** Scaffold was integrated during the augmented marrow stimulation technique following microfracture

Postoperative Rehabilitation and Follow-up

Each patient underwent a 3-week immobilization period in a neutral position, utilizing a short-leg splint for stabilization. After the removal of the splint, patients began physical therapy exercises to enhance ankle mobility and were permitted to bear partial weight on the affected limb. Based on radiographic evidence of union, patients were advised to progress to full weight-bearing between 6 to 8 weeks post-surgery. Patients underwent monthly radiographic evaluations until the complete union was confirmed, after which they were permitted to resume all daily activities without restrictions.

Clinical and radiological evaluations

At the final follow-up, all participants were subjected to both clinical and radiographic evaluations. Functional outcomes were assessed using the American Orthopaedic Foot and Ankle Society (AOFAS) scale both before the surgery and at the last follow-up. In cases involving osteochondral autograft transplantation (OAT), the Lysholm Knee Score was utilized to ascertain the postoperative status of the knee. Serial radiographic analyses via plain x-rays of the ankle were conducted to monitor the healing process at the osteotomy site, assess any displacement, detect potential graft subsidence, and evaluate the progression of osteoarthritis (OA) throughout the follow-up period. The progression of OA post-treatment in the ankle was evaluated with the Kellgren-Lawrence grading scale. [12] Preoperative magnetic resonance imaging (MRI) of the ankle was employed to determine the dimensions and severity of the chondral lesions across all cases, utilizing the Hepple classification system to categorize the osteochondral lesions of the talus (OLT) based on MRI findings. [13] Any adverse outcomes, including wound complications, ankle instability, infection, synovitis, or non-union at the osteotomy site were meticulously documented during the follow-up. The surgeon who provided treatment was not informed about the clinical and radiological assessments to ensure an unbiased evaluation.

Statistical analysis

The analysis involved a descriptive examination of both continuous and categorical data, utilizing methods such as proportions, frequency distributions, means, and standard deviations. To compare independent variables, the study applied either the student's t-test or the Mann-Whitney U test based on the assessment of normal distribution conformity. Intra-group differences were evaluated using the Wilcoxon-Signed-Rank test. The Chi-square test was employed for the comparison of categorical variables. A p-value of less than 0.05 was considered to denote statistical significance.

Results

The study included 55 patients (24 males and 31 females) with a mean age of 40.7±12.6 (range, 18-66) years. Four patients underwent bilateral operations at different times; thus, a total of 59 ankles were analyzed, with 22 undergoing AMIC treatment and 37 undergoing OAT. Several demographic and clinical characteristics, including age (p:0.791), sex (p:0.356), lesion size (p:0.192), grade (p:0.177), and preoperative AOFAS score (p:0.288), were comparable between the groups, with no significant statistical differences. Lesion grades ranged from 3 to 5, with the majority being grade 5 in both groups. Preoperative Ankle-Hindfoot scores (AOFAS) were similar, suggesting comparable baseline functional statuses. Notably, the AMIC group reported a longer follow-up period (78.0 months) compared to the OAT group (40.2 months), indicating a significant difference (p=0.001) (Table 1).

Postoperative evaluations revealed an improvement in AOFAS scores for both groups, with the AMIC group achieving a postoperative score of 90.8 and the OAT group slightly higher at 93.1, although this difference was not statistically significant (p=0.467). The OAT group demonstrated excellent outcomes with an average postoperative Lysholm Knee Score of 98.4 ± 2.8, indicating a low rate of donor site morbidity. Additionally, in terms of osteoarthritis (OA) progression, 19 ankles in the AMIC group and 36 in the OAT group were evaluated as Grade 0, showing no progression to OA (p:0.141). Complication rates

were low, with only one reported in the AMIC group (4.3%) (Table 2). The only postoperative complication noted was a non-union at the site of the medial malleolar osteotomy. A subsequent revision surgery was performed, leading to the achievement of successful bone healing.

Table 1. Demographic and clinical characteristics of patients.

Variables	AMIC Group n:21 patients (22 ankles)	Mosaicplasty Group N: 34 patients (37 ankles)	p-value
Age (year±SD)	40.1±13.2	41.0±12.5	0.791[1]
Sex (M/F)	8/13	16/18	0.356[2]
Side (R/L)	14/8	9/28	0.003[2]
Lesion Size AP (mm±SD)	14.5±3.5	13.9±4.0	0.558[1]
Lesion Size ML (mm±SD)	11.7±3.2	10.3±2.9	0.096[1]
Lesion Size Area (cm2±SD)	1.7±0.6	1.4±0.6	0.192[1]
Lesion MRI Grade (n)			0.177[2]
Grade 3	7	5	
Grade 4	7	11	
Grade 5	8	21	
Preoperative AOFAS (points±SD)	44.0±15.4	43.8±9.2	0.288[3]
Follow-up (months±SD)	78.0±11.9	40.2±24.6	0.001[3]

[1] Student t-test [2] Chi-square test [3] Mann-Whitney U test SD: Standard deviation, M: Male, F: Female, AP: Anteroposterior, ML: Mediolateral, R: Right, L: Left AMIC: Augmented Matrix-induced Chondrogenesis, AOFAS: American Orthopaedic Foot & Ankle Society, MRI: Magnetic Resonance Imaging.

Table 2. Comparison of outcome measures.

Variables	AMIC Group	Mosaicplasty Group	p-value
Preoperative AOFAS (points±SD)	44.0±15.4	43.8±9.2	0.288[1]
Postoperative AOFAS (points±SD)	90.8±10.1	93.1±6.2	0.467[1]
p-value	0.001[2]	0.001[2]	
LKS (score±SD, range)	-	98.4±2.8 (90-100)	NA
OA Grade (n)			0.141[3]
Grade 0	19	36	
Grade I	3	1	
Complications (n, %)	1 (4.3%)	0 (0%)	0.373[3]

[1] Mann Whitney U test [2] Wilcoxon Signed Rank Test [3] Chi-Square Test, SD: Standard deviation, M: Male, F: Female, AP: Anteroposterior, ML: Mediolateral, R: Right, L: Left, AMIC: Augmented Matrix-induced Chondrogenesis, AOFAS: American Orthopaedic Foot & Ankle Society, LKS: Lysholm Knee Score

Discussion

This study presents a comparative analysis of Autologous Matrix-Induced Chondrogenesis (AMIC) and Osteochondral Autologous Transplantation (OAT) in the treatment of osteochondral lesions of the talus. Our findings reveal that both methods are equally effective, showing similar improvements in AOFAS scores and osteoarthritis progression. Despite some differences in lesion location and follow-up times, both treatments provide comparable functional outcomes, significantly contributing to our understanding and management of OLTs.

In discussing our study on Autologous Matrix-Induced Chondrogenesis (AMIC) for osteochondral lesions of the talus, we engage in a detailed comparison with the existing literature, highlighting both congruences and discrepancies in findings.

Gao et al.'s systematic review provides an overview of the existing literature on AMIC procedures in the knee, hip, and ankle with relatively low Coleman methodology scores for studies on all three joints (knee: 57.8, ankle: 55.3, hip: 57.7) highlighting the need for higher-quality research and direct comparisons with other treatments to better understand AMIC's effectiveness. [14] Additionally, Toale et al.'s systematic review noted good midterm outcomes for osteochondral lesions of the talus but raised concerns about the long-term repair of tissue surface damage. [15] Our study addresses these gaps by providing a comprehensive evaluation of the AMIC technique with a longer average follow-up of 78.0 months compared to shorter follow-ups in existing studies.

Migliorini et al. observed improved outcomes in their study focusing on AMIC treatment, evidenced by higher scores in AOFAS, Visual Analogue Scale (VAS), and Tegner score, though specific values for a direct comparison were not provided. [16] This finding is in line with a review by Bruns et al., which highlighted a weighted mean AOFAS score of 82 in AMIC treatments, indicating a general trend of functional improvement in various studies. [8] However, in contrast to these positive trends, our study, with a longer follow-up duration (78.0 months compared to 43.5) and a lower complication rate (4.3% non-union), shows a notable difference from the 10% revision surgery rate for persistent pain reported in Migliorini et al.'s study.

In the research conducted by Becher et al., which compared AMIC with microfracture procedures, did not find significant differences in outcomes, suggesting that the addition of a

collagen I/III matrix might not offer added benefits. [17] This contrasts with our findings, where the AMIC group showed a substantial improvement in AOFAS scores from a preoperative average of 44.0 to a postoperative 90.8. This discrepancy might be attributed to differences in technique application or patient selection criteria.

Weigelt et al. reported a high complication rate in their study, with 52% cartilage hypertrophy and a 58% reoperation rate primarily due to surgical hardware issues. [18] In stark contrast, our study noted a significantly lower complication rate, with only one case of non-union at the medial malleoli osteotomy site, representing 4.3% of our study group. This comparison emphasizes the variability in AMIC outcomes depending on specific methodologies and patient populations.

In the study by Baums et al. a high failure rate of 40% was noted, largely due to incomplete defect filling and the development of subchondral bone cysts/osteophytes. [19] Our results showed a much lower failure rate in the AMIC group exhibiting no progression to osteoarthritis, suggesting a more successful outcome with our approach.

Regarding demographic profiles, our AMIC group had an average age of 40 years, with a gender distribution of 8 males and 13 females, showing a slight female predominance. This contrasts with the study by Valderrabano et al. (which included patients with a mean age of 33 years, predominantly male (18 males and 8 females). [11] Despite these differences, both studies reported significant improvements in AOFAS scores postoperatively.

Turning to the OAT group in our study, we observed a significant improvement in functional outcomes, with an average postoperative Ankle-Hindfoot score (AOFAS) of 93.1, and an excellent Lysholm Knee Score of 98.4. When compared to the literature, our results are consistent with the positive outcomes reported in various studies. A systematic review by Shimozono et al. of 11 studies on 500 ankles treated with OAT system showed an 87.4% rate of excellent or good results at a 62.8-month follow-up, with donor site morbidity observed in 3.6% of patients. [20] Kennedy's research highlighted significant short-term improvements in foot and ankle outcome scores, with a considerable number of patients (42 of 72) regaining their pre-injury sports activity levels. [21] This parallels our findings in terms of functional recovery. Furthermore, the study by Scranton et al., which tracked 50 patients over 36 months, reported a high rate of good or excellent outcomes in individuals treated with autologous osteochondral grafts. [22] Baltzer and Arnold also achieved good and excellent results in nearly all of their 43 patients, which is consistent with our study's high success rate. [23] They highlighted the importance of graft size, a factor that we also consider crucial in our procedures. Similarly, Hangody's extensive 17-year prospective study reinforced these positive results, noting that a majority of patients (92%) experienced outcomes ranging from good to excellent following OAT procedure. [24] This long-term perspective adds depth to our understanding of the procedure's effectiveness over time.

Conversely, Valderrabano et al. presented a contrast, with moderate clinical results in 57% (12 out of 21) of patients treated with OAT for talar OLT. [25] This variance might stem from differences in patient demographics or lesion characteristics. Notably, Valderrabano et al. also observed postoperative complications, such as Subchondral bone cysts, in a significant 66% of their patients, which was a concern not notably present in our study.

Addressing the issue of donor site morbidity, our study's findings contrast with those of Reddy et al. who observed a notable incidence of knee discomfort and donor site morbidity, affecting about 37% of their patient group. [26] Similarly, significant donor site morbidity was reported by LaPrade and Botker in two cases, where hypertrophic fibrocartilage formation at the graft harvest sites was linked to knee pain and locking. [27] Woelfle et al. found a higher donor-site morbidity associated with advanced age, a factor we also consider in our patient selection. [28] Lastly, A meta-analysis on donor site morbidity indicated a morbidity rate ranging from 6.7% to 10.8%, which is higher than what we observed. [29] This discrepancy might be due to different surgical techniques or patient management protocols.

This significant rate of morbidity points to the potential challenges in autograft harvesting. Conversely, our results align more closely with the findings from Hangody and Fuels, who reported considerably lower rates of donor site morbidity, approximately 3%, in a large-scale study involving 831 patients. [30] The study by Kennedy et al. further supports this lower morbidity rate, revealing minimal donor site morbidity among a group of 72 patients, with only about 4% reporting significant discomfort. [21]

Our study's retrospective design presents inherent limitations, including potential biases in data collection and analysis. The small sample size may affect the generalizability of the results. Additionally, the significant difference in follow-up periods

between the AMIC and OAT groups (78.0 vs. 41.0 months) may influence the comparison of the long-term outcomes. Only one postoperative complication was reported, which may not fully represent the potential risks associated with these treatments.

In conclusion, this retrospective study indicates that both AMIC and OAT procedures are effective in improving Ankle-Hindfoot scores without significant differences in osteoarthritis progression. The slightly higher score in the OAT group was not statistically significant. The overall low complication rate is encouraging; however, more extensive, prospective studies with uniform follow-up periods are needed for a more definitive evaluation of these treatments.

Ethical Approval

Ethical approval for this study was obtained from institutional review board.

Declaration of Conflicting Interests

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References

1. Flick AB, Gould N. Osteochondritis dissecans of the talus (transchondral fractures of the talus): review of the literature and new surgical approach for medial dome lesions. Foot Ankle. 1985 Jan-Feb;5(4):165-85.
2. Giannini S, Buda R, Grigolo B, Vannini F. Autologous chondrocyte transplantation in osteochondral lesions of the ankle joint. Foot Ankle Int. 2001 Jun;22(6):513-7.
3. Verhagen RA, Struijs PA, Bossuyt PM, van Dijk CN. Systematic review of treatment strategies for osteochondral defects of the talar dome. Foot Ankle Clin. 2003 Jun;8(2):233-42, viii-ix.
4. Abu-Shakra M, Buskila D, Shoenfeld Y. Osteonecrosis in patients with SLE. Clin Rev Allergy Immunol. 2003 Aug;25(1):13-24.
5. Shearer C, Loomer R, Clement D. Nonoperatively managed stage 5 osteochondral talar lesions. Foot Ankle Int. 2002 Jul;23(7):651-4.
6. Tol JL, Struijs PA, Bossuyt PM, Verhagen RA, van Dijk CN. Treatment strategies in osteochondral defects of the talar dome: a systematic review. Foot Ankle Int. 2000 Feb;21(2):119-26.
7. Wang CC, Yang KC, Chen IH. Current treatment concepts for osteochondral lesions of the talus. Tzu Chi Med J. 2020 Oct 5;33(3):243-249.
8. Bruns J, Habermann C, Werner M. Osteochondral Lesions of the Talus: A Review on Talus Osteochondral Injuries, Including Osteochondritis Dissecans. Cartilage. 2021 Dec;13(1_suppl):1380S-1401S.
9. antzen C, Ebskov LB, Johansen JK. AMIC Procedure for Treatment of Osteochondral Lesions of Talus-A Systematic Review of the Current Literature. J Foot Ankle Surg. 2022 Jul-Aug;61(4):888-895.
10. Hannon CP, Bayer S, Murawski CD, Canata GL, Clanton TO, Haverkamp D, et al.; International Consensus Group on Cartilage Repair of the Ankle. Debridement, Curettage, and Bone Marrow Stimulation: Proceedings of the International Consensus Meeting on Cartilage Repair of the Ankle. Foot Ankle Int. 2018 Jul;39(1_suppl):16S-22S.
11. Valderrabano V, Miska M, Leumann A, Wiewiorski M. Reconstruction of osteochondral lesions of the talus with autologous spongiosa grafts and autologous matrix-induced chondrogenesis. Am J Sports Med. 2013 Mar;41(3):519-27.
12. Kellgren JH, Lawrence JS. Radiological Assessment of Osteo-Arthrosis. Ann Rheum Dis 1957; 16: 494–502.
13. Hepple S, Winson IG, Glew D. Osteochondral lesions of the talus: a revised classification. Foot Ankle Int. 1999 Dec;20(12):789-93.
14. Gao L, Orth P, Cucchiarini M, Madry H. Autologous Matrix-Induced Chondrogenesis: A Systematic Review of the Clinical Evidence. Am J Sports Med. 2019 Jan;47(1):222-231.
15. Toale J, Shimozono Y, Mulvin C, Dahmen J, Kerkhoffs GMMJ, Kennedy JG. Midterm Outcomes of Bone Marrow Stimulation for Primary Osteochondral Lesions of the Talus: A Systematic Review. Orthop J Sports Med. 2019 Oct 30;7(10):2325967119879127.
16. Migliorini F, Eschweiler J, Maffulli N, Schenker H, Driessen A, Rath B, et al. Autologous Matrix Induced Chondrogenesis (AMIC) Compared to Microfractures for Chondral Defects of the Talar Shoulder: A Five-Year Follow-Up Prospective Cohort Study. Life (Basel). 2021 Mar 16;11(3):244.
17. Becher C, Malahias MA, Ali MM, Maffulli N, Thermann H. Arthroscopic microfracture vs. arthroscopic autologous matrix-induced chondrogenesis for the treatment of articular cartilage defects of the talus. Knee Surg Sports Traumatol Arthrosc. 2019 Sep;27(9):2731-2736.
18. Weigelt L, Hartmann R, Pfirrmann C, Espinosa N, Wirth SH. Autologous Matrix-Induced Chondrogenesis for Osteochondral Lesions of the Talus: A Clinical and Radiological 2- to 8-Year Follow-up Study. Am J Sports Med. 2019 Jun;47(7):1679-1686.

19. Baums MH, Schultz W, Kostuj T, Klinger HM. Cartilage repair techniques of the talus: An update. World J Orthop. 2014 Jul 18;5(3):171-9.
20. Shimozono Y, Hurley ET, Myerson CL, Kennedy JG. Good clinical and functional outcomes at mid-term following autologous osteochondral transplantation for osteochondral lesions of the talus. Knee Surg Sports Traumatol Arthrosc. 2018 Oct;26(10):3055-3062.
21. Kennedy JG, Murawski CD. The Treatment of Osteochondral Lesions of the Talus with Autologous Osteochondral Transplantation and Bone Marrow Aspirate Concentrate: Surgical Technique. Cartilage. 2011 Oct;2(4):327-36.
22. Scranton PE Jr, Frey CC, Feder KS. Outcome of osteochondral autograft transplantation for type-V cystic osteochondral lesions of the talus. J Bone Joint Surg Br. 2006 May;88(5):614-9.
23. Baltzer AW, Arnold JP. Bone-cartilage transplantation from the ipsilateral knee for chondral lesions of the talus. Arthroscopy. 2005 Feb;21(2):159-66.
24. Hangody L, Dobos J, Baló E, Pánics G, Hangody LR, Berkes I. Clinical experiences with autologous osteochondral mosaicplasty in an athletic population: a 17-year prospective multicenter study. Am J Sports Med. 2010 Jun;38(6):1125-33.
25. Valderrabano V, Leumann A, Rasch H, Egelhof T, Hintermann B, Pagenstert G. Knee-to-ankle mosaicplasty for the treatment of osteochondral lesions of the ankle joint. Am J Sports Med. 2009 Nov;37 Suppl 1:105S-111S.
26. Reddy S, Pedowitz DI, Parekh SG, Sennett BJ, Okereke E. The morbidity associated with osteochondral harvest from asymptomatic knees for the treatment of osteochondral lesions of the talus. Am J Sports Med. 2007 Jan;35(1):80-5.
27. LaPrade RF, Botker JC. Donor-site morbidity after osteochondral autograft transfer procedures. Arthroscopy. 2004 Sep;20(7):e69-73.
28. Woelfle JV, Reichel H, Nelitz M. Indications and limitations of osteochondral autologous transplantation in osteochondritis dissecans of the talus. Knee Surg Sports Traumatol Arthrosc. 2013 Aug;21(8):1925-30.
29. Shimozono Y, Seow D, Yasui Y, Fields K, Kennedy JG. Knee-to-Talus Donor-Site Morbidity Following Autologous Osteochondral Transplantation: A Meta-Analysis with Best-case and Worst-case Analysis. Clin Orthop Relat Res. 2019 Aug;477(8):1915-1931.
30. Hangody L, Füles P. Autologous osteochondral mosaicplasty for the treatment of full-thickness defects of weight-bearing joints: ten years of experimental and clinical experience. J Bone Joint Surg Am. 2003;85-A Suppl 2:25-32.