FussSprungg 17 (2019) 11—20

Online verfügbar unter www.sciencedirect.com

ScienceDirect

Fuß & Sprunggelenk

www.elsevier.com/locate/fuspru

Special Issue Original Article

Mid-term (4—7 years) results of matrix-associated stem cell transplantation (MAST) in chondral defects of the first metatarsophalangeal joint

Mittelfristige (4-7 Jahre) Ergebnisse der Matrix-Assoziierten Stammzelltransplantation (MAST) bei Knorpeldefekten am Großzehengrundgelenk

Martinus Richter*,[1], Stefan Zech, Stefan Andreas Meissner, Issam Naef

Department for Foot and Ankle Surgery Rummelsberg and Nuremberg, Schwarzenbruck, Germany

Received 9 November 2018; accepted 24 January 2019
Available online 14 February 2019

KEYWORDS
Cartilage defect;
Stem cell;
Collagen matrix;
Matrix-associated stem cell transplantation;
First metatarsophalangeal joint

Summary

Background: Matrix-associated stem cell transplantation (MAST) has shown good short-term results for treatment of chondral defects at first metatarsophalangeal joint (MTP1). The aim of the study was to assess mid-term results (≥4-year-follow-up).

Materials and methods: In a prospective consecutive non-controlled clinical follow-up study, 61 patients with 81 chondral defects at MTP1 that were treated with MAST from October 1, 2011 to October 31, 2014 were analysed. Degree of osteoarthritis, range of motion (ROM), size and location of the chondral defects, pedographic parameters, and the Visual Analogue Scale Foot and Ankle (VAS FA) before treatment and at follow-up were registered and analysed. Bone marrow aspirate was harvested from the ipsilateral pelvic bone marrow and centrifuged (10 min, 1500 RPM). The supernatant was used to impregnate a collagen I/III matrix (Chondro-Guide, Geistlich, Wollhusen, Switzerland). The matrix was fixed into the chondral defect with fibrin glue.

Results: Following mean (range) values were registered at time of surgery: age 44 (35—72) years, VAS FA 49.4 (12.3—82.3), ROM 20.4/0/8.4° (dorsiflexion/plantarflexion), degree of osteoarthritis 1.9 (1—3). The 81 chondral defects were located as follows, dorsal metatarsal head, $n = 28$ (35%), plantar metatarsal head, $n = 12$ (15%); dorsal & plantar, $n = 21$ (26%); medial sesamoid, $n = 14$ (17%); lateral

* Corresponding author: Martinus Richter, MD, PhD, Department for Foot and Ankle Surgery Rummelsberg and Nuremberg, Location Hospital Rummelsberg, Rummelsberg 71, 90592 Schwarzenbruck, Germany. Tel.: +49 9128 50 43450; fax: +49 9128 50 43260.
E-Mail: martinus.richter@sana.de (M. Richter).
[1] http://www.foot-surgery.eu/

https://doi.org/10.1016/j.fuspru.2019.01.004

sesamoid, $n = 6$ (7%) (two defects, $n = 14$, three defects, $n = 3$). The defect size was 0.9 (.5—3.0) cm^2. Fifty-six patients (92%) completed follow-up at 62 (48—84) months. VAS FA increased to 82.5 (45.6—100; t-test, $p < .01$). ROM increased to 30.2/0/15.4 ($p = .05$). Degree of osteoarthritis decreased to 1.1 (0—3, $p = .04$).
Conclusions: The surgical treatment of chondral defects at MTP1 including MAST led to improved clinical scores, ROM and degree of osteoarthritis after 4—7 years. No adverse effects of MAST were registered. Even though a control group is missing, we conclude that MAST is an effective method for the treatment of chondral defects at MTP1.

SCHLÜSSELWÖRTER
Knorpeldefekt;
Stammzelle;
Kollagenmatrix;
Matrix-Assoziierte Stammzelltransplantation;
Großzehengrundgelenk

Zusammenfassung

Hintergrund: Die Matrix-Assoziierte Stammzelltransplantation (MAST) hat gute kurzfristige Ergebnisse bei der Therapie von Knorpeldefekten am Großzehengrundgelenk (MTP1) gezeigt. Ziel dieser Studie war die Analyse von mittelfristigen Ergebnissen (≥4-Jahre-Nachuntersuchung).
Material und Methoden: In einer prospektiven konsekutiven unkontrollierten Nachuntersuchungsstudie wurden 61 Patienten mit 81 Knorpeldefekten an MTP1, die mit MAST von 01.10.2011 bis 31.10.2014 behandelt wurden, analysiert. Arthrosegrad, Bewegungsumfang (ROM), Größe und Lokalisation des Knorpeldefekts, pedographische Parameter und Visual Analog Skala Fuß und Sprunggelenk (VASFA) wurden präoperativ und bei der Nachuntersuchung registriert und analysiert. Knochenmarkpunktat wurde am gleichseitigen Beckenkamm gewonnen und zentrifugiert (10 Minuten mit 1.500 Umdrehungen/Minute). Mit dem zellreichen Überstand wurde eine Kollagen-I/III-Matrix (Chondro-Gide) imprägniert. Diese Matrix wurde mit Fibrinkleber und die Knorpeldefekte eingeklebt.
Ergebnisse: Zum OP-Zeitpunkt wurden folgende Mittelwerte (Spannweite) registriert: Alter 44 (35-72) Jahre, VAS FA 49,4 (12,3-82,3), ROM 20,4/0/8,4° (Dorsalextension/Plantarflektion), Arthrosegrad 1.9 (1-3). Die 81 Knorpeldefekte waren wie folgt lokalisiert: Metatarsalekopf dorsal, n = 28 (35%); Metatarsalekopf plantar, n = 12 (15%); dorsal & plantar, n = 21 (26%), mediales Sesambein, n = 14 (17%), laterales Sesambein, n = 6 (7%) (zwei Defekte, n = 14; drei Defekte, n = 3). Die Defektgröße betrug 0,9 (0,5-3,0) cm^2. Sechsundfünfzig Patienten (92%) wurden nach 62 (48-84) Monaten nachuntersucht. VAS FA stieg auf 82.5 (45.6-100; t-test, p<.01). ROM stieg auf 30.2/0/15.4 (p=.05). Der Arthrosegrad verringerte sich auf 1.1 (0-3, p=.04).
Schlussfolgerungen: Die operative Behandlung von Knorpeldefekten and MTP1 mit MAST führte zu verbesserten Scores, ROM und Arthrosegrad nach 4-7 Jahren. Unerwünschte Ereignisse wurden nicht registriert. Auch unter Berücksichtigung der fehlenden Kontrollgruppe schlussfolgern wir, dass MAST eine effektive Methode für die Therapie von Knorpeldefekten an MTP1 darstellt.

Introduction

The optimal treatment for chondral defects at foot and ankle is debatable including the first metatarsophalangeal joint (MTP1) [1]. Principle possible options are distraction, debridement, abrasion, microfracture, antegrade or retrograde drilling, mosaicplasty or osteochondral autograft transfer system (OATS), autologous chondrocyte implantation (ACI), matrix-induced autologous chondrocyte implantation (MACI), autologous matrix-induced chondrogenesis (AMIC), allologous stem cell transplantation, allograft bone/cartilage transplantation, or matrix-associated stem cell transplantation (MAST) [2—12]. Most of those options have been used first or even exclusively in the ankle [2—12]. MAST was described as a modification of AMIC with a potentially higher concentration of stem cells in the implanted matrix, and also as a completely new method [4,13]. MAST was also used at MTP1 with encouraging 2-year-results [1,4]. The aim of this study was to assess mid-term results (≥4-year-follow-up) of MAST at MTP1.

Material and methods

Technique [1]

MAST was performed as single open procedure associated with additional surgical procedures

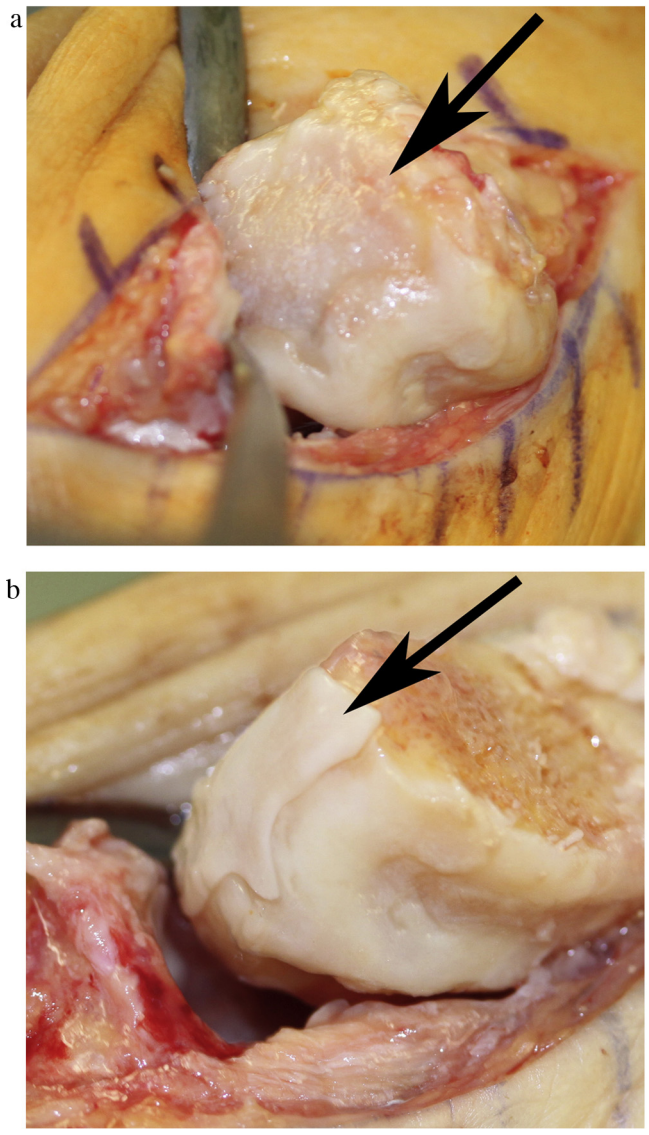

Fig. 1. (a and b) Chondral defect at the first metatarsal head (a). The defect was specified as dorsally located, and the size 2.1 × 2.3 cm (a). Figure b shows the matrix (black arrow) in place.

(cheilectomy, synovectomy, arthrolysis and tenolysis) [1]. Fig. 1 shows a typical case with dorsal chondral defect. Figs. 2 and 3 show different cases with plantar chondral defect (Fig. 2) or with additional chondral defect at the medial sesamoid (Fig. 3). Bone marrow aspirate was harvested during the procedure from the ipsilateral pelvic bone marrow with a Jamshidi needle (10 × 3 mm, Cardinal, Dublin, OH, USA) and a special syringe (Arthrex-ACP, Arthrex, Naples, FL, USA) through a stab incision. The syringe was centrifuged (10 min, 1500 rotations per minute). The supernatant, i.e. bone marrow aspirate concentrate (BMAC), was used to impregnate a collagen I/III matrix (Chondro-Guide, Geistlich, Wollhusen, Switzerland) that was cut to the size of the cartilage defect before. The cartilage defect was debrided until stable surrounding cartilage was present when possible (Fig. 1b, plantar side; Fig.s 2b, medial, lateral and dorsal side; Fig. 3b, all sides). Microfracturing with a 1.6 mm Kirschner wire was performed. The matrix with stem cells was fixed into the chondral defect with fibrin glue (Tissucoll, Deerfield, IL, USA or Tisseel, Baxter, Unterschleissheim, Germany). When the chondral defect reached the limit of the chondral region, the matrix was placed 3 mm over this limit (Fig. 1b, dorsal; Fig. 2b, plantar; Fig. 3d, all sides). In chondral defects comprising the entire chondral surface at the sesamoid, the matrix covered the entire previous chondral surface (Fig. 3d). An 8Ch drainage was inserted without suction. Closure was performed following the local standard with layer wise closure (joint capsule, subcutaneous, skin). The postoperative treatment included full weight

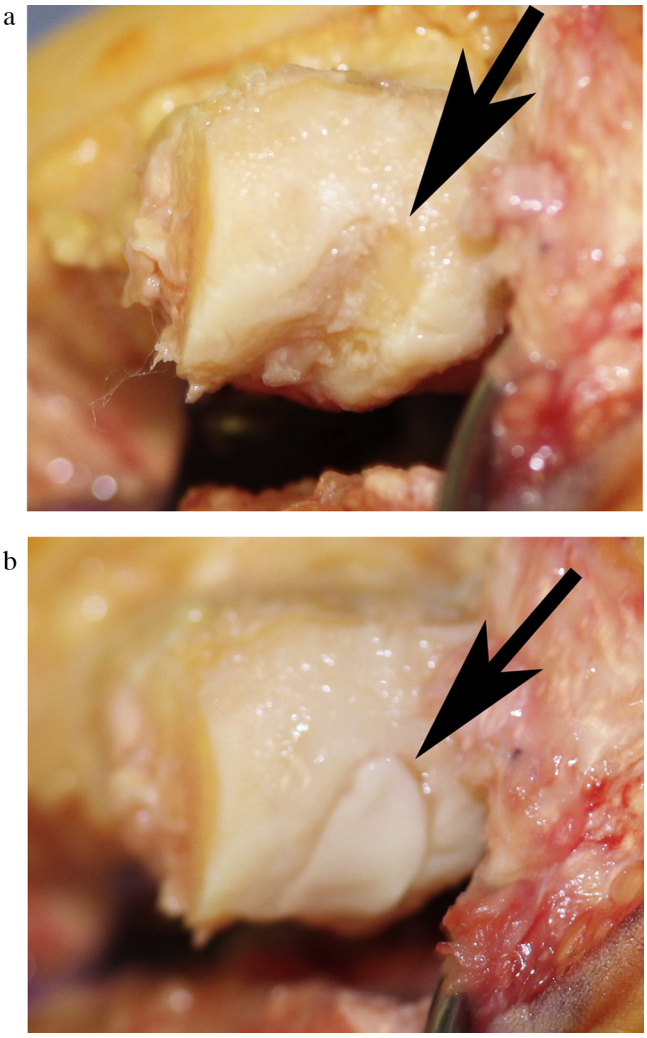

Fig. 2. (a and b) Chondral defect at the first metatarsal head (a). The defect (black arrow) was specified as plantarly located, and the size 0.8 × 2.7 cm (a). Figure b shows the matrix (black arrow) in place.

bearing without orthosis or splint. Motion of the joint especially with dorsiflexion was started at the day of surgery. The patients were instructed to perform motion of the joints with MAST 10 times a day for 10 min. Postoperative consultations were performed at 6 weeks, 3, 12 and 24 months.

Study design

In a prospective consecutive non-controlled clinical follow-up study, 61 patients with 81 chondral defects at the 1st MTP1 that were treated with MAST from October 1, 2011 to October, 31, 2014 were analysed. The data was extracted from a prospectively acquired database starting November 1, 2011 including all operatively treated patient at the authors' institution. The single inclusion criteria for the study was the described procedure. Patients with bilateral treatment ($n = 42$) or with corrective osteotomies for hallux valgus correction or others ($n = 214$) were excluded. No other exclusion criteria were defined. In contrast to the previous study cohort, we also considered chondral defects at the sesamoids to be addressed with MAST in the patients during the last year of the inclusion period [1]. Range of motion (ROM) was measured clinically with a goniometer. All patients had radiographs (bilateral views (dorsoplantar and lateral) with full weight bearing) or weight-bearing computed tomographies (WBCT). The degenerative changes were classified in four degrees [14]. Pedography was performed as described below. There were no limitations in terms of patient's age and defect size. There was no clear and objective definition regarding the combination of defect size, location and age. The indication for the procedure was based on patient history, clinical investigation and degree of osteoarthritis (Stages 1–3) [14]. Stage 4 was considered as contraindication for the procedure. Visual Analogue Scale

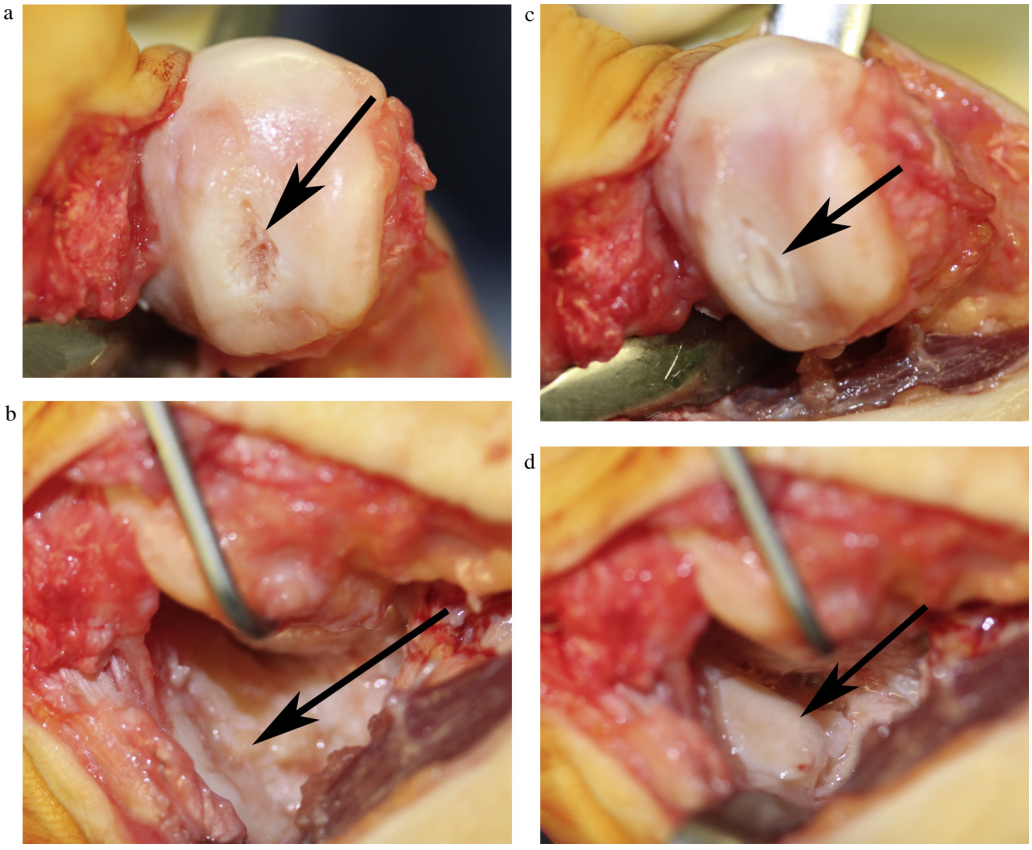

Fig. 3. (a—d) Chondral defect at the first metatarsal head (a) and the medial sesamoid (b). The defect at the metatarsal (black arrow) was specified as plantarly located, and the size 0.8 × 0.5 cm (Figure aa). The defect at the medial sesamoid (black arrow) was specified as size 1.2 × 1 cm (b). Figures c and d show the matrix (black arrow) in place.

Foot and Ankle (VAS FA) was registered [15,16]. The defect size and location were assessed intraoperatively. The defects were classified as dorsal when located above a virtual horizontal line at 50% of the metatarsal head height or diameter; plantar when located below that line, or both when crossing the line. The following parameters were registered at follow-up: VAS FA, ROM, degree of osteoarthritis and pedographic parameters.

Pedography

Standard dynamic pedography (three trials, walking, third step, mid stance force pattern) was performed as described before (Fig. 4) [17—19]. A standard platform (Emed AT®, Novel Inc., Munich, Germany & St. Paul, MN, USA) and software (Emed ST®, version 12.3.18, Novel Inc., Munich, Germany & St. Paul, MN, USA) was used. Both sides were measured. Computerized mapping to create a distribution into the following foot regions was performed with the standard software (Automask, version 12.3.18, Novel Inc., Munich, Germany & St. Paul, MN, USA): hindfoot, midfoot, first metatarsal head/sesamoids, second metatarsal head, third metatarsal head, fourth metatarsal head, fifth metatarsal head, first toe, second toe, third to fifth toe. This mapping process does not include manual determination of landmarks [20]. Parameters of first metatarsal head and first toe were compared preoperative versus follow-up [19].

Statistics

An unpaired *t*-test was used for statistical comparison of VAS FA and maximum pedographic pressures preoperatively and at follow-up, and a Chi2-test for all other parameters. Before using the paired *t*-test, the data were investigated regarding the distribution and the data were proven to be normally distributed.

Results

Sixty-one patients with 75 chondral defects were included in the study. The age of the patients was 44 years on average (range, 35—72 years),

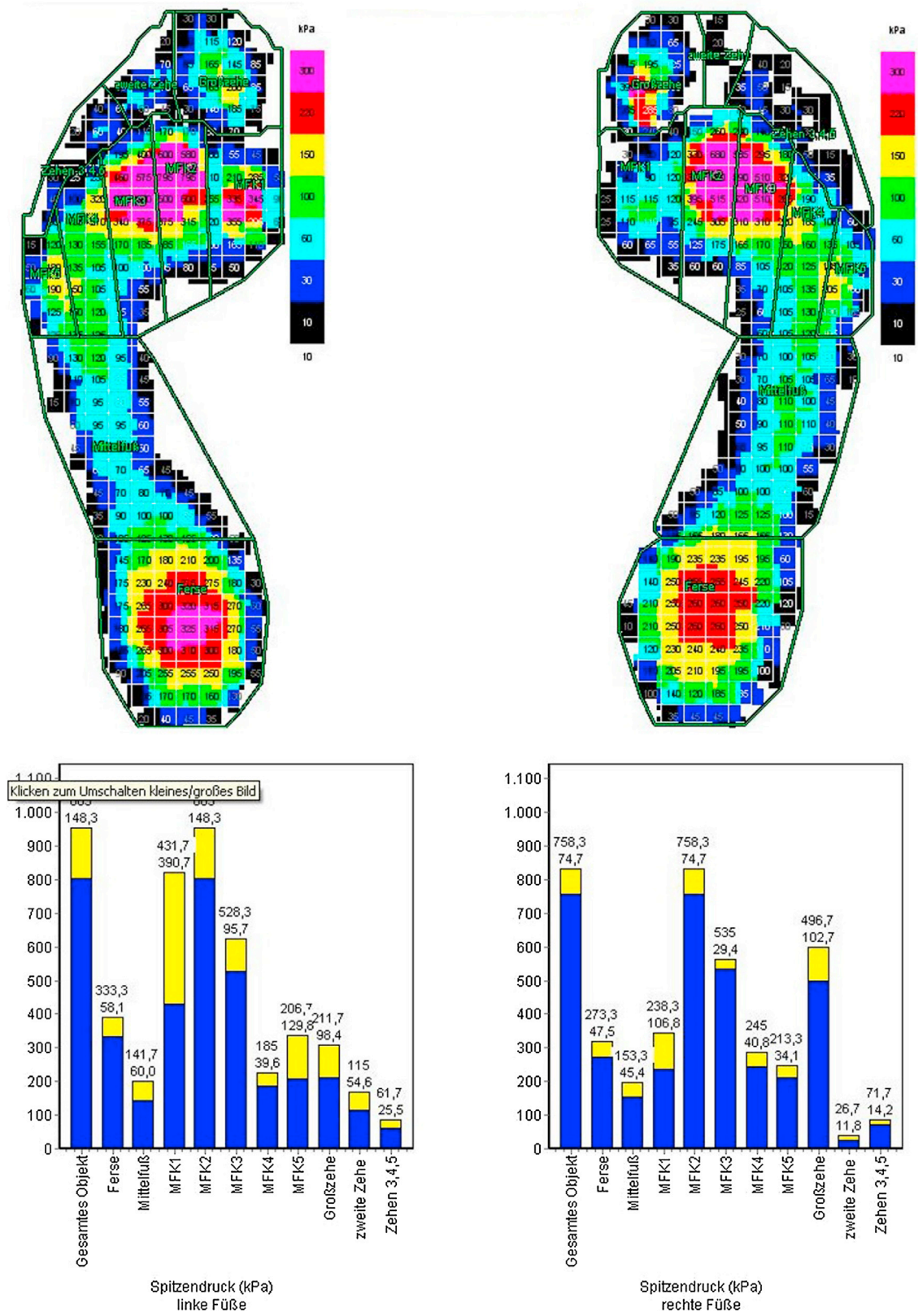

Fig. 4. Pedographic pattern at 5-year-follow-up (left foot; physiological pressure at the first toe ("Großzehe") and first metatarsal head/sesamoids ("MFK1") in comparison with normal controls), in comparison with untreated condition (right foot; not included in the study; increased pressure at the first toe ("Großzehe") and decreased pressure at the first metatarsal head/sesamoids ("MFK1") in comparison with normal controls).

Table 1 Radiographic degree of osteoarthritis preoperatively and at follow-up [14].

Stage	Preoperatively	Follow-up
0	0	15 (27%)
1	21 (34%)	24 (43%)
2	28 (46%)	15 (27%)
3	12 (20%)	2 (4%)
4	0	0

39 (64%) were male. VAS FA before surgery was 49.4 (range, 12.3—82.3). In 32 cases (52%), the right foot was affected. Table 1 shows the degree of osteoarthritis. The most common stage was 2 ($n = 28$, 46%). Mean ROM was 20.4/0/8.4°. Table 2 shows the pedographic parameters. The maximum pressure was 237.7 kPa at the first metatarsal head/sesamoids and 807.1 kPa at the first toe on average. This represents increased pressure at the first toe and decreased pressure at the first metatarsal head/sesamoids in comparison with normal controls (Fig. 4). The 81 chondral defects were located as follows, dorsal metatarsal head, $n = 28$ (35%); plantar metatarsal head, $n = 12$ (15%); dorsal & plantar, $n = 21$ (26%); medial sesamoid, $n = 14$ (17%); lateral sesamoid, $n = 6$ (7%) (two defects, $n = 14$, three defects, $n = 3$). No chondral defects were detected at the joint surface of the base phalanx. The defect size was 0.9 cm^2 (range, .5—3.0). No complications were registered until follow-up. Four patients (7%) were converted to arthrodesis and 1 (2%) to total joint replacement. These 5 patients (8%) were considered as bad results and were not included in follow-up examination for this study. Fifty-six patients (92%) completed follow-up at 62 months on average (range, 48—84). VAS FA improved to 82.5 (range, 45.6-100; *t*-test, $p < .01$). ROM improved to 30.2/0/15.4 ($p = .05$). Degree of osteoarthritis improved to 1.1 on average (range, 0—3, Chi2-test, $p = .04$) and stage 2 was the most common (Table 1). The maximum pressure and the percentage of maximum force of the maximum force of the entire foot increased at the first metatarsal and decreased the first toe (Table 2, Fig. 4, all $p < .01$). This represents physiological pressure at the first toe and first metatarsal head/sesamoids in comparison with normal controls (Fig. 4).

Discussion

Cheilectomy, synovectomy, arthrolysis and tenolysis are the standard procedure for joint preserving surgery in hallux rigidus, i.e. chondral defects at MTP1 [1,14,21—23]. These studies have shown good but not optimal with pain and functional restrictions [1,21—23]. Later conversion to arthrodesis were described in up to 16% in the short- to midterm follow-up [23]. As attempt to improve the outcome, we added MAST for the chondral defect(s) based on our previous experience with MAST and hallux rigidus surgery [1,4]. Despite many studies focused on treatment of cartilage defects at the ankle, no such methods were utilized for the MTP1 so far [1,4]. Furthermore, the use of these methods in other joints of the foot has not been described so far [4]. Recently studies dealing with implantation of a polyvinyl alcohol plug were published showing good results [24]. None of the previous studies, considered chondral defects at the sesamoids.

Table 2 Pedographic parameters preoperatively and at follow-up.

Parameter	Preoperatively Mean (range)	Follow up Mean (range)	Test *p*
FMHS, percentage maximum Force of entire foot (%)	27.5 3—69	65.4 35—87	Chi2 <.01
FMHS, maximum pressure (kPa)	243.9 22—763	759.3 443—987	*t*-Test <.01
First toe, percentage maximum Force of entire foot (%)	82.5 34—100	19.2 11—45	Chi2 <.01
First toe, maximum pressure (kPa)	877.2 545—987	247.8 32—789	*t*-Test <.01

FMTS, first metatarsal head/sesamoids. The individual percentages of the maximum force of the entire force represent the percentage of the maximum force measured in the in the corresponding area (FMTS or first toe) of the maximum force of the entire force (100% means that the maximum force of the corresponding area is similar to the maximum force of the entire foot). The individual maximum pressure values represent the mean values of the maximum pressure measured in the three different trials in the corresponding area (FMTS or first toe).

Our results are favourable and no adverse effects have been registered. This is the first study analysing mid-term results with MAST [1]. The scores improved, ROM increased, and the pedographic parameters were normalised. We were able to compare with our 2-year-results from an earlier study [1]. The degree of osteoarthritis decreased at follow-up when compared with the preoperative stage [14]. We did not see differences when comparing with two-year-results and conclude that the improved degree of osteoarthritis remains stable between 2- and 7-year-follow-up. This classification is based on radiographs, and is focused on extent of osteophytes and joint space between first metatarsal and base phalanx [1,14]. It is not surprising at all that removal of osteophytes and cheilectomy changes the extend of osteophytes which is part of the classification [1]. However, the width of the joint space which is also part of the classification was also changed, i.e. widened [1,14]. As concluded after the two-year-follow-up study, we confirm based on the 4—7-year results that the MAST procedure and not the osteophyte removal/cheilectomy is the reason for the joint space widening [1]. The used classification does not give any direct information about the cartilage as such as sufficient MRI with thin slice thickness could give [1,14]. It does also not give any information about the joint space, i.e. degree of osteoarthritis between metatarsal head and sesamoids [14]. This was irrelevant for the previous study because only chondral defect at the metatarsal head were treated [1]. In the current cohort we also considered chondral defects at the sesamoid for MAST which is not reflected by the classification [14].

We were extremely interested in histological specimens of the transplants. Five patients (8%) with failed restoration of MTP1 were undertaken surgery again so far in which histological specimens were harvested. Histological assessment gave anecdotal but clear evidence that the transplanted cells could develop or better determine into chondrocytes, and that the implanted collagen matrix stayed in place and acts as a scaffold for the chondrocytes as in "real" cartilage [4,25]. Only one of the above mentioned studies dealing with cartilage restoration addressed MTP1, and none included a validated outcome score which makes a comparison with our results difficult from a scientific point of view [24]. The study addressing the MTP1 compared cartilage defects with implantation of a polyvinyl alcohol plug compared with arthrodesis, and the conclusion of the study was that implantation of a polyvinyl alcohol plug and arthrodesis were equivalent. When comparing length and rate of follow-up, our results have the same typical 2-year-follow-up with a 100% follow-up rate [24]. The score based results seem to be comparable based on the fact that different scores were used [24]. Regarding functional assessment, we would again like to point out that this an investigation including validated pedographic parameters [1]. Preoperatively, we registered increased pressure at the first toe and decreased pressure at the first metatarsal head/sesamoids in comparison with normal controls (Fig. 4). We registered improvement of function, i.e. pressure distribution in the gait stance phase which was not shown by the above mentioned study [24]. At follow-up we found physiological pressure at the first toe and first metatarsal head/sesamoids in comparison with normal controls (Fig. 4). Our results seem to be better than with cheilectomy alone which was the main goal of the introduced method [1,21—23]. Especially, improvement of validated score, validated functional assessment and low conversion rate to arthrodesis (0%) is superior to previously reported results of cheilectomy alone [1,21—23]. We want point out the inclusion of chondral defects at the sesamoids in our treatment. After initial favourable results, we expanded the indication to this chondral surface, and based on the current study results we do recommend to consider the sesamoids for treatment with MAST [4].

Technical considerations

We consider MAST as a combination of stem cell transplantation and AMIC [4]. An almost similar method was introduced for the ankle as completely novel method [13]. The advantage in comparison with AMIC which uses peripheral blood is the higher concentration of pluripotent cells or stem cells. No one knows the exact concentration of stem cells which varies for different age and location [4,26]. Rough estimations name 0.1% stem cells as concentration in the peripheral blood and 3% in the pelvic bone marrow in young adults [4,26,27]. This deduces that the cells should be harvested from the pelvic bone marrow which is part of MAST [4]. Centrifugation is a useful method to double the concentration of the cells, and the MAST includes a typical centrifugation (1500 RPM for 10 min) that potentially doubles the concentration of stem cells in the supernatant to 6%, typically called BMAC [4]. As in MACI, MAST uses a carrier or scaffold for the cells [4]. Different scaffold are available, some with hyaluronic acid, and others with collagen [4]. MAST includes a collagen matrix (Chondro-Gide®, Geistlich, Baden-Baden, Germany) [4]. This scaffold is manufactured out of denaturised collagen from the pig, and contains collagen I and III. The

matrix has two layers (bilayer). The superficial layer is "cell occlusive", i.e. blood cells including the potential stem cells cannot penetrate this layer [4]. The deep layer is porous [4]. The superficial, "cell occlusive" layer should prevent penetration of the cells into the joint space, and the deep, porous layer should contain and maintain the cells, and should integrate in part with the underlying subchondral bone [4]. The microfracturing is added to add cells and nutritious supply from the underlying bone (marrow), as use in microfracture alone [4]. The fibrin glue is added to give sufficient initial stability for early functional after treatment [4]. Our strategy is to fit the matrix as exact and as stable as possible [4]. The main advantage of MAST in comparison with ACI and MACI is the single procedure methodology and lower cost [4]. The advantage in comparison with AMIC is the potential higher concentration of stem cells or better pluripotent cells [4]. The advantage of the Chondro-Guide in comparison with other scaffolds/matrices used (hyaluronic acid) is the more physiological content and structure [4]. This matrix gives the initial stability to allow the early stimulation of the transplanted cells by joint motion which induces the determination of the transplanted stem cells into chondrocytes [4]. Furthermore, it gives the collagen scaffold which seems to be extremely difficult to determine from stem cells by an in vivo stimulation [4].

Limitations

Limitations of the study are: small patient number, debatable indication for treatment, associated procedures, no control group, short follow-up, and missing outcome parameter for the created tissue. All patients with corrective osteotomies at the forefoot and combination with MAST at the MTP1 were excluded from the study because we wanted to exclude any effect of a correction on the result. Much more patients ($n = 214$) were excluded from the study due to corrective osteotomies than patients ($n = 61$) included without corrective osteotomies. Furthermore, patients with bilateral treatment ($n = 42$) were excluded. A missing control group is always a methodological shortcoming as in many other studies that we cannot invalidate. The follow-up time of 4—7 years for a modified or new technique seems appropriate, and we are not aware of any other study with longer follow-up. When indicating MAST, we did not follow a clear and objective definition regarding the combination of defect size, location and age. The indication was finally made intraoperatively and subjectively by the surgeon. There is an ongoing debate about the different epidemiology and definition of chondral defects at MTP1 versus osteoarthritis versus hallux rigidus [1,14,21—24]. This study is focused and chondral defects at MTP1, and we are not interested in discussing different epidemiology, definition or specifications as outlined above. We detected chondral defects at the dorsal part of the metatarsal head as described for hallux rigidus, as well as plantar chondral defects at the metatarsal head and even chondral defects at the sesamoids that were previously not considered at all or at least not for hallux rigidus specification [1,14,21—24]. To date, we treat more and more chondral defects at the sesamoids with MAST, and in the majority of the cases as additional procedure during hallux valgus correction. This also reflected by the high number of cases with MAST at MTP1 ($n = 214$) that were excluded from this study because of additional hallux valgus correction.

Regarding assessment of the created tissue, we did not obtain histological specimens in the follow-up cohort which would be optimal from a scientific point of view. As described above, we could only harvest histological specimens during conversion to fusion or total joint replacement, i.e. in cases with failed joint preservation. Based on our experience regarding MRI based assessment of chondral lesions at the ankle, we used our validated score as principal outcome parameter and not MRI findings [1,16].

In conclusion, the surgical treatment of chondral defects at MTP1 including MAST led to improved clinical scores, degree of osteoarthritis and ROM after 4-7 years. Even though a control group is missing, we conclude that MAST is an effective method for the treatment of chondral defects at MTP1.

Conflict of interest

None of the authors or the authors' institution received funding in relation to this study. The corresponding author is consultant of Curvebeam, Geistlich, Intercus, Ossio, shareholder of Curvebeam, and proprietor of R-Innovation.

References

[1] Richter M, Zech S, Andreas Meissner S. Matrix-associated stem cell transplantation (MAST) in chondral defects of the 1st metatarsophalangeal joint is safe and effective-2-year-follow-up in 20 patients. Foot Ankle Surg 2017;23(3):195—200.

[2] Tay LX, Ahmad RE, Dashtdar H, Tay KW, Masjuddin T, Ab-Rahim S, et al. Treatment outcomes of alginate-embedded allogenic mesenchymal stem cells versus autologous chondrocytes for the repair

of focal articular cartilage defects in a rabbit model. Am J Sports Med 2012;40(1):83—90.
[3] Giannini S, Buda R, Battaglia M, Cavallo M, Ruffilli A, Ramponi L, et al. One-step repair in talar osteochondral lesions: 4-year clinical results and t2-mapping capability in outcome prediction. Am J Sports Med 2013;41(3):511—8.
[4] Richter M, Zech S. Matrix-associated stem cell transplantation (MAST) in chondral defects of foot and ankle is effective. Foot Ankle Surg 2013;19(2):84—90.
[5] Niemeyer P, Salzmann G, Schmal H, Mayr H, Sudkamp NP. Autologous chondrocyte implantation for the treatment of chondral and osteochondral defects of the talus: a meta-analysis of available evidence. Knee Surg Sports Traumatol Arthrosc 2011;20(9):1696—703.
[6] Giza E, Sullivan M, Ocel D, Lundeen G, Mitchell ME, Veris L, et al. Matrix-induced autologous chondrocyte implantation of talus articular defects. Foot Ankle Int 2010;31(9):747—53.
[7] Giannini S, Buda R, Grigolo B, Bevoni R, Di Caprio F, Ruffilli A, et al. Bipolar fresh osteochondral allograft of the ankle. Foot Ankle Int 2010;31(1):38—46.
[8] Hangody L, Fules 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.
[9] Richter M, Zech S. 3D-imaging (ARCADIS) based computer assisted surgery (CAS) guided retrograde drilling in osteochondritis dissecans of the talus. Foot Ankle Int 2008;29(12):1243—8.
[10] van Roermund PM, Marijnissen AC, Lafeber FP. Joint distraction as an alternative for the treatment of osteoarthritis. Foot Ankle Clin 2002;7(3):515—27.
[11] Benthien JP, Behrens P. Autologous matrix-induced chondrogenesis (AMIC): combining microfracturing and a collagen I/III matrix for articular cartilage resurfacing. Cartilage 2010;1(1):65—8.
[12] Gobbi A, Francisco RA, Lubowitz JH, Allegra F, Canata G. Osteochondral lesions of the talus: randomized controlled trial comparing chondroplasty, microfracture, and osteochondral autograft transplantation. Arthroscopy 2006;22(10):1085—92.
[13] Giannini S, Buda R, Vannini F, Cavallo M, Grigolo B. One-step bone marrow-derived cell transplantation in talar osteochondral lesions. Clin Orthop Relat Res 2009;467(12):3307—20.
[14] Shereff MJ, Baumhauer JF. Hallux rigidus and osteoarthrosis of the first metatarsophalangeal joint. J Bone Joint Surg Am 1998;80(6):898—908.
[15] Stuber J, Zech S, Bay R, Qazzaz A, Richter M. Normative data of the Visual Analogue Scale Foot and Ankle (VAS FA) for pathological conditions. Foot Ankle Surg 2011;17(3):166—72.
[16] Richter M, Zech S, Geerling J, Frink M, Knobloch K, Krettek C. A new foot and ankle outcome score: questionnaire based, subjective, Visual Analogue Scale, validated and computerized. Foot Ankle Surg 2006;12(4):191—9.
[17] Inman VT, Ralston HJ, Todd F. Human walking. Baltimore: Williams & Wilkins; 1981.
[18] Alexander IJ, Chao EY, Johnson KA. The assessment of dynamic foot-to-ground contact forces and plantar pressure distribution: a review of the evolution of current techniques and clinical applications. Foot Ankle 1990;11(3):152—67.
[19] Richter M, Frink M, Zech S, Vanin N, Geerling J, Droste P, et al. Intraoperative pedography: a validated method for static intraoperative biomechanical assessment. Foot Ankle Int 2006;27(10):833—42.
[20] Cavanagh PR, Ulbrecht JS, Caputo GM. Elevated plantar pressure and ulceration in diabetic patients after panmetatarsal head resection: two case reports. Foot Ankle Int 1999;20(8):521—6.
[21] Vanore JV, Christensen JC, Kravitz SR, Schuberth JM, Thomas JL, Weil LS, et al. Diagnosis and treatment of first metatarsophalangeal joint disorders. Section 2: Hallux rigidus. J Foot Ankle Surg 2003;42(3):124—36.
[22] Coughlin MJ, Shurnas PS. Hallux rigidus. J Bone Joint Surg Am 2004;86-A(Suppl 1 (Pt 2)):119—30.
[23] Harrison T, Fawzy E, Dinah F, Palmer S. Prospective assessment of dorsal cheilectomy for hallux rigidus using a patient-reported outcome score. J Foot Ankle Surg 2010;49(3):232—7.
[24] Baumhauer JF, Singh D, Glazebrook M, Blundell C, De VG, Le IL, et al. Prospective, randomized, multi-centered clinical trial assessing safety and efficacy of a synthetic cartilage implant versus first metatarsophalangeal arthrodesis in advanced hallux rigidus. Foot Ankle Int 2016, http://dx.doi.org/10.1177/1071100716635560.
[25] Richter M, Zech S, Andreas Meissner S. Matrix-associated stem cell transplantation (MAST) in chondral defects of the ankle is safe and effective — 2-year-followup in 130 patients. Foot Ankle Surg 2017;23(4):236—42.
[26] Kishimoto S, Ishihara M, Mori Y, Takikawa M, Hattori H, Nakamura S, et al. Effective expansion of human adipose-derived stromal cells and bone marrow-derived mesenchymal stem cells cultured on a fragmin/protamine nanoparticles-coated substratum with human platelet-rich plasma. J Tissue Eng Regen Med 2012;10.
[27] Dashtdar H, Rothan HA, Tay T, Ahmad RE, Ali R, Tay LX, et al. A preliminary study comparing the use of allogenic chondrogenic pre-differentiated and undifferentiated mesenchymal stem cells for the repair of full thickness articular cartilage defects in rabbits. J Orthop Res 2011;29(9):1336—42.