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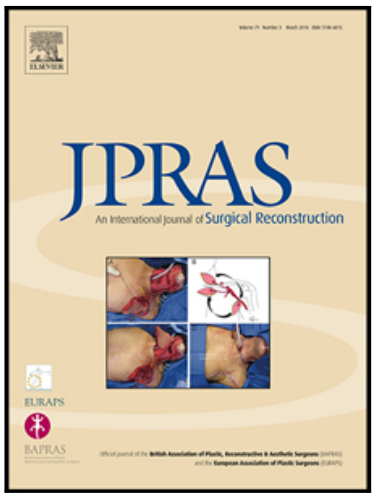
Published in:
Journal of Plastic, Reconstructive and Aesthetic Surgery

DOI:
10.1016/j.bjps.2018.09.007

Publication date:
2019

Document version:
Accepted manuscript



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PII: S1748-6815(18)30332-2
DOI: https://doi.org/10.1016/j.bjps.2018.09.007
Reference: PRAS 5802

To appear in: *Journal of Plastic, Reconstructive & Aesthetic Surgery*

Received date: 21 March 2018
Revised date: 3 September 2018
Accepted date: 10 September 2018

Please cite this article as: NM Toyserkani MD PhD , CH Jensen MSc PhD , S Tabatabaeifar MD , MG Jørgensen BSc , S Hvidsten MSc , JA Simonsen MD , DC Andersen MSc PhD , SP Sheikh MD DMSc , JA Sørensen MD PhD , Adipose-derived regenerative cells and fat grafting for treating breast cancer-related lymphedema: Lymphoscintigraphic evaluation with one year follow-up, *Journal of Plastic, Reconstructive & Aesthetic Surgery* (2018), doi: https://doi.org/10.1016/j.bjps.2018.09.007

Adipose-derived regenerative cells and fat grafting for treating breast cancer-related lymphedema: Lymphoscintigraphic evaluation with one year follow-up

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Keywords:

Breast cancer-related lymphedema; Adipose-derived regenerative cells, stromal vascular fraction, pilot study, lymphoscintigraphy,

Financial disclosure:

The study was funded by participating departments as well as the Axel Muusfeldt foundation. None of the authors have any financial interest regarding this paper.

Abstract

Background:

Breast cancer-related lymphedema (BCRL) is a feared late complication. Present treatment options are lacking. Recent studies have suggested that mesenchymal stromal cells can alleviate lymphedema. Herein, we report the results from the first human pilot study with adipose-derived regenerative cells (ADRC) for treating BCRL with one year follow-up.

Material and methods:

We included ten BCRL patients. ADRCs were injected directly into the axillary region together with a scar releasing fat graft procedure. Primary endpoint was change in arm volume. Secondary endpoints were change in patient reported outcome, lymphoscintigraphy changes and safety.

Results:

During follow up, no significant change in volume was noted. Patient reported outcomes improved significantly over time. Five patients reduced their use of conservative management. Quantitative lymphoscintigraphy did not improve on the lymphedema affected arms. ADRCs were well-tolerated and only minor transient adverse events related to liposuction were noted.

Conclusions:

In this pilot study, a single injection of ADRC improved lymphedema based on patient reported outcome measures and there were no serious adverse events in the follow-up period. Lymphoscintigraphic evaluation showed no improvement after ADRC treatment. There was no change in excess arm volume. Results of this trial need to be confirmed in randomized clinical trials.

Evidence Rating Scale for Therapeutic Studies: Level IV

Introduction

Breast cancer-related lymphedema (BCRL) is one of the most frequent and serious late complications following breast cancer surgery with axillary lymph node involvement as up to 1/3 of patients develop BCRL [1]. While several microsurgical techniques have been presented over the last decades, they continue to be somewhat experimental due to the lack of clear evidence and therefore conservative management remains the standard of care. Preclinical and sparse clinical studies have suggested that cell therapy using autologous mesenchymal stromal cells from various sources including adipose tissue, muscle, and bone marrow can alleviate lymphedema [2]. The two studies performed so far in humans have been with cells derived from bone marrow [3, 4].

We were the first to demonstrate the initial 6 months feasibility and safety of transplanting adipose-derived regenerative cells (ADRCs) combined with fat grafting in 10 patients with BCRL (NCT02592213/ [5]). Herein we report the outcomes after 12 months which now include follow-up quantitative lymphoscintigraphy results evaluating the lymph drainage following ADRCs treatment.

Material and Methods

Study design and eligibility criteria

We conducted a prospective open label, single-arm and single-center feasibility and safety study evaluating ADRC injection and fat grafting for treatment of BCRL. Initially we screened 34 potential participants and enrolled 11 patients. One patient was subsequently excluded due to non-protocolled treatment; hence, results from ten patients are reported. Inclusion of patients began in November 2015 with the treatments given between January 2016 and May 2016.

The eligibility criteria for participation were: Age between 18 – 70 years, unilateral BCRL, International Society of Lymphology (ISL) stage I or II [6], recurrence free disease for minimum one year, circumference difference of either upper or lower arm of 2cm between healthy and lymphedema arm, American Society of Anesthesiologists physical status score 1 or 2, written informed consent and the ability to understand the Danish language. The exclusion criteria were: History of other cancer types, diabetes mellitus, psychiatric conditions that could interfere with participation and tobacco use, which was not ceased in relation to the procedure.

Approvals

The study was approved by The Regional Committees on Health Research Ethics for Southern Denmark (S-20150109). The study was also registered with the Danish Data Protection Agency (2008-58-0035) and registered at Clinicaltrials.gov before inclusion of the first patient (NCT02592213). All patients gave written informed consent before participation. ADRC preparation was carried out in an authorised tissue establishment (Danish Health and Medicines Authority, Authorisation no. 29035) for the handling of human tissues and cells at Odense University Hospital, Denmark.

The experimental procedure

All procedures have previously been described in detail [5]. Briefly, liposuction was performed under general anesthesia without local anesthetics, as the effect of these on ADRC viability is uncertain [7]. We aimed to obtain 300 mL of lipoaspirate for ADRC isolation and 30 mL of lipoaspirate for fat grafting. The ADRC isolation was performed using an automated processing Celution® 800/CRS system (Cytori Therapeutics, San Diego, California, USA) per the manufacturer´s instructions. The final cell suspension was transferred into a 5mL syringe of which 1 mL was used for cell characterization and 4 mL for transplantation.

The lipoaspirate for grafting was decanted for 15 minutes and injected in a fan shaped pattern into the axilla with a sharp cannula to release scar tissue. No further scar releasing measures were done. The isolated ADRCs were injected in eight predefined points in the axilla adjacent to the axillary scar, in the same area where fat grafting was performed. In each point 0.5 mL of the suspension was injected using a 25-gauge cannula for a total of 4 mL. The treatment was given as a same-day procedure.

Cell characterization

Total viable nucleated cell recovery and viability percentage were determined using the Nucleocounter NC100 (ChemoMetec, Allerod, Denmark). Cellular components were identified by flow cytometry analysis with a panel of cell surface markers (CD34, CD90, CD31, CD73, CD235a-CD45-CD31-CD34+ and CD235a-CD45-CD31+CD34+) in agreement with International Federation for Adipose Therapeutics and Science (IFATS) and the International Society for Cellular Therapy (ISCT) recommendations [8].

Endpoints

Patients were evaluated 1, 3, 6 and 12 months after the ADRC injection and fat grafting. The primary endpoint was change in arm volume. Secondary endpoints were change in patient reported outcomes, change in lymph drainage, and safety evaluation.

Volume estimation

The volume of each arm was calculated based on two methods; multiple circumference measurements (1, 3, 6 and 12 months) and Dual-energy X-ray absorptiometry (DXA) (3, 6 and 12 months). The excess arm volume was defined as the volume difference between the two arms for both methods. As previously described [9], circumference measurements were made at five points on each arm; wrist, largest point on lower arm, elbow, middle of upper arm and proximal on the upper arm. The length between each point was measured and at each time point the same sites were used. Based on these five measurements, the arm was divided into four segments and the volume of each segment was calculated based on the truncated cone formula:

$$V = \frac{h\left(C_1^2 + C_1C_2 + C_2^2\right)}{12\pi}$$

Where V is the segment volume, h is the length of the segment and C_1 and C_2 are the two circumference measurements at the two ends of the segment. Arm volume was calculated as the sum of the four segmental volumes.

The DXA was performed as two whole body scans with the patient lying in a modified supine position enabling the arm to be separated from the trunk. For analysis, a blinded assessor drew the region around the arm with the proximal end of the arm defined as just below the deltoid muscle. As previously described, the bone mineral content, fat mass and lean mass were used to calculate a total arm volume based on known densities [10].

Patient reported outcomes

All patient reported outcomes were evaluated at 1, 3, 6 and 12 months. Patients were asked to rate the feeling of heaviness and tension in the lymphedema arm on numerical rating scales ranging from 0 to 10 with 0 meaning no heaviness/tension at all and 10 signifying the worst heaviness/tension imaginable [11]. Additionally, two questionnaires were used; the Disabilities of

the Arm, Shoulder and Hand (DASH) outcome questionnaire [12] as well as the Lymphedema Quality-of-Life Questionnaire (LYMQOL) [13].

Lymphoscintigraphy

Lymphoscintigraphy was performed according to a procedure described in detail elsewhere [14, 15]. The procedure was performed before treatment and 12 months later.

In brief, we injected 20 MBq technetium-99m-labelled human serum albumin (Tc-99m-HSA [Vasculocis, CIS bio international, Paris, France]) in 0.1 mL into the finger web between the 2nd and 3rd fingers bilaterally. We obtained sequential five-minute scans every 30-45 minutes for five hours. After drainage from injection site into the collecting lymphatic vessels the Tc-99m-HSA tracer mimics the lymph fluid flow through the arm. The mean transit time (MTT) of the tracer was calculated for each arm as previously described [14]. The MTT is a quantitative measure of the time at which the lymph fluid traverses the arm. We compared the baseline- and postoperative MTT.

Statistical analyses

Continuous data were described as mean±SD (standard deviation) and non-parametric data were described by median (IQR (interquartile range)). Patient reported outcomes were analyzed with Friedman's test for multiple non-parametric comparisons with Dunn's post-hoc test for multiple comparisons. Volumetric changes were analyzed by One-way ANOVA with Dunnett post-hoc test for multiple comparisons. Agreement between the two volumetric measurements was tested using Bland-Altman plot. MTT were analyzed with paired or unpaired t-test. Two-way ANOVA was performed with Tukey’s test for multiple comparisons for subgroup analysis. A two-tailed p-value of less than 0.05 was considered statistically significant. Statistical analyses were performed using Prism 6 (GraphPad Software, La Jolla, CA, USA).

Results

Ten patients (median 55 years, range 34-68) had unilateral BCRL with a median duration of 28.5 months (IQR 17.3 months), and were in a stable phase of their conservative management, see Supplemental Table 1 for baseline data. For the ADRC treatment 252g±42g of adipose tissue was harvested for cell isolation, from either the abdomen or thighs depending on availability and preference of the patient. Preliminary six months results have previously been published [5]. The ADRC isolation and characterization using the automated Celution® system were comparable to previous results [16] (Supplemental Table 2). We injected 5.41 x 10^7±0.97 x10^7 ADRCs and 28.1 mL ±7.8 mL lipoaspirate into the axillary region to release scar tissue. The viability of the cells was 83.4, 3.0 % (mean, SD) and 24.9, 8.0 % (mean, SD) of the cells were defined as stromal stem cells based on surface markers CD45-CD34+CD31-.

We measured the change in excess arm volume over time using two different methods (DXA and multiple circumference measurements). Although differences in absolute volume were present between the results obtained from the two methods, there was good agreement between the two measurements (Figure 1A). There was no significant decrease in arm volume as estimated by either of the two methods over the 12-month period (Figure 1B-C). Subgroup analyses based on ISL stage revealed a tendency towards better volumetric outcomes evaluated with DXA for stage I compared with stage II patients (p=0.0858) (Supplemental Figure 1).

In general, the patients reported a decrease of their lymphedema symptoms over time. The median (IQR, n=10) score for heaviness of the arm was 5.5(4.0) at baseline, 2.5(4.3) after 6 months and 2.0(4.5) after 12 months (p<0.0001) (Figure 1D). Likewise, we found the median score for arm tension to be 5.0(1.5) at baseline, 2.5(4.3) after 6 months and 2.0(3.0) (p=0.0054) after 12 months (Figure 1E). The DASH questionnaire was also used in which the median score was 21.3(23.5) at baseline, 12.9(26.0) after 6 months and 13.3(28.5) after 12 months (p=0.0061) (Figure 1F). Finally,

the LYMQOL questionnaire showed a significant improvement in the symptoms subscale after 12 months (p=0.0150). The other subscales failed to meet significance level at 12 months follow-up. For an overview of all results see Supplemental Table 3.

Moreover, five patients reduced their use of conservative treatment in the follow-up period (one discontinued all therapy, one reduced the size of compression garment, one reduced the use of compression garment and two no longer needed to wear compression on the hand). Four patients experienced problems with recurrent skin infections in the year prior to treatment but no one had any infections in the follow-up period.

We used lymphoscintigraphy to quantitate any change in lymph flow. Before ADRC transplantation, the MTT was 63.4±26.8 minutes on the lymphedema and 5.4±2.6 minutes on the contralateral healthy arm. Twelve months following treatment, MTT was 60.7±36.8 minutes and 7.9±3.0 minutes on the lymphedema and the contralateral healthy arm, respectively. There was a clear significant difference between the two arms both before and after treatment (Figure 2A-B, p=0.0020)). The group difference between pre- and postoperative MTT on the lymphedema arm was insignificant (p=0.6884) (Figure 2C), while on the healthy arm there was a significant increase in MTT (p=0.0006) (Figure 2D).

No serious adverse events were noted. Minor short term adverse events have been reported previously [5]. During the study period one patient was diagnosed with a contralateral non-palpable breast cancer as part of routine mammography screening ten months following ADRC injection. No episodes of recurrence were detected.

Discussion

In this study, we aimed to examine the feasibility and safety of ADRC transplantation combined with fat grafting for treating BCRL. The treatment resulted in significant overall improvement in patient reported outcome measures. Importantly, the procedure was safe even in the setting of previous cancer in the axillary region. Another benefit was that none of the four patients with recurrent skin infections experienced any infections in the 12 months follow-up period, which is similar to results achieved by microsurgical procedures [17].

The positive results were not reflected in the arm volume measurements. One explanation for this could be that patients were already in a stable phase with physiotherapeutic management, and the excess volume was at least to some extent due to chronic changes. The majority of patients had very limited pitting and were ISL stage II patients [6]. Subgroup analysis revealed a tendency for better results for ISL stage I patients in line with previous studies of microsurgical procedures suggesting better efficacy for lower stages [18] . In addition, conservative management is a known confounder when treating lymphedema, as volumetric changes can be attributed to this treatment rather than the surgical procedure [19].

The lack of clear objective measures to document a beneficial effect of therapeutic procedures has limited the translation of especially microsurgical procedures [20, 21]. This is partly due to a lack of accepted quantitative measures for lymph drainage. The only previous lymphoscintigraphic results following cell therapy have been reported by Quián et al [22], who described two cases of lower extremity lymphedema following MS-MSCs therapy. After cell therapy, they showed increased activity in proximal lymph nodes as well as greater extent of dermal back flow, which was interpreted as improvement. However, this evaluation was merely qualitative. We used quantitative lymphoscintigraphy to estimate MTT to evaluate the lymph drainage following ADRC injection. We found no change in mean MTT following ADRC treatment on the lymphedema arm, whereas

we showed a slight increase (worsening) on the healthy arms. We are left to speculate if this worsening was caused by a systemic reaction to the treatment or merely expresses inherent variability of the method. Our comparisons were limited by the fact that in two cases, the preoperative MTT was not accurately estimated and only a minimum MTT value was estimated resulting in a “false” low preoperative MTT. Consequently, we may have underestimated the improvement in these two cases, who both had much faster MTT postoperatively. The varying results between the patients could indicate different responses to the treatment or it could represent an inherent insecurity in the reproducibility of the MTT estimation. The very small although significant changes on the healthy side suggest that the MTT estimation is very reproducible but further studies need to document this. Overall, our results fit well with the qualitative interpretations of the scintigraphies which did not show any major differences pre- and postoperatively.

Our procedure of ADRC enriched fat grafting differed from the usually described method, where the ADRC and fat graft is mixed before injection to secure a proper mix of the two components [23]. Instead, we opted to first inject the lipoaspirate and later same day inject the ADRC. This was done purely for logistic reasons to avoid a prolonged general anesthesia and occupation of the operating room. It can be speculated whether this approach hampered the effect of the treatment. To our knowledge these two approaches have not previously been compared. Further studies are needed to examine if this is of importance.

The main limitations of our study were the lack of a control group and the low number of included patients. In general lymphedema is either stable or worsens over time but very rarely improves without additional intervention, meaning that any improvement is likely due to the given intervention [24]. However, the lack of a control group and the open label design leads to high risk of bias when evaluating the outcome. Our subgroup analysis was limited due to the low number of patients, but it did at least hint at how patient selection for future trials could be optimized, in that

ISL stage I patients seemed more likely to have a positive outcome. It will be interesting to follow these patients further and if possible offer re-treatment as previous studies have suggested a linear relationship between fat grafting and clinical improvement in radiation induced tissue damage [25].

In conclusion, the results from this study suggest that autologous ADRC transplantation together with fat grafting is safe with possible long-term efficacies. Using adipose tissue as the source of autologous non-cultured adult stem cells for BCRL treatment is appealing, as it is obtainable in large quantities with minimal discomfort and allows for a safe, minimal invasive surgical procedure. The next step towards routine clinical translation is to perform a randomized blinded placebo-controlled trial. It is important to document long term safety in the transition towards clinical use of ADRCs [26].

Conflicts of interest

There were no conflicts of interest related to this paper.

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Figure legends

Figure 1: Change in excess arm volume and patient reported outcomes.

A) There was good agreement between volume measurements obtained by multiple circumference measurements and DXA, although DXA scan trended towards estimated a greater volume difference between arms. Dashed lines symbolize 95 % confidence interval. B) There was no significant change in excess arm volume measured by DXA (results shown as means±SEM). C) There was only a slight decrease in excess arm volume after one month calculated by multiple circumference measurements, but this decrease did not persist and excess arm volume was near identical to baseline after 12 months (results shown as means±SEM). There was a clear reduction in patient reported outcomes with regards to heaviness (D), tension (E) and the DASH questionnaire (F) (results shown as median (IQR)).

Figure 2: Change in lymphoscintigraphy parameters.

A) The graphs illustrate representative results from a patient with improvement in the quantitative measure of lymph function, mean transit time (MTT). The first graphs (left) illustrate the time activity curve from the injection depot (red, lymphedema arm, blue, healthy arm. The second graphs (middle left) show the time activity curve of the arm. The third graphs (middle right) show the resulting input function modelling the amount of activity entering the arm from the injection depot. The fourth graphs (right) show the retention function calculated based on the previous graphs in which the area under the curve corresponds to MTT. There is a clear reduction in the area under the curve for this patient, who no longer used any conservative management and felt great relief regarding the patient reported outcomes. B) The graphs illustrate representative results from a patient without any improvement in the MTT estimation. This patient had a decrease in arm volume and improvement in patient reported outcomes, but it did not correspond with any noteworthy

change in MTT: C) There was no significant difference in mean MTT on the lymphedema arm before and after treatment (results shown as means±SEM). D) There was a small but significant increase in MTT on the healthy arm after treatment (results shown as means±SEM).

Supplemental Figure 1: Results grouped by lymphedema stage.

Patients were grouped based on the proposed staging by the International Society of Lymphology (ISL) into stage I (n=2) and II (n=8). Two-way ANOVA statistical analysis was used to compare the two groups over time, and time points were all compared with the baseline measurements. The patient reported outcomes shown are for feeling of heaviness (A) and tension (B) in the arm during the 12 months follow-up (data shown as median, IQR) A decrease for both ISL stage I and II was seen for the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire that was only significant for stage II most likely due to small number of patients (C) (data shown as median, IQR). The change in excess arm volume for both DXA (D) and multiple circumference measurements (E) is shown and a trend was seen towards greater effect for Stage I data shown as mean, standard error. *: $p<0.05$, **: $p<0.01$, ***: $p<0.001$.

Table legends

Supplemental Table 1

Table 1S. Overview of baseline characteristics of included patients. BMI = Body mass index , CT = Chemotherapy = (+, yes, -, no), ISL stage = International Society of Lymphology stage, , RT = Radiation therapy (+, yes, -, no),. Patient ID 02 was excluded due to non-protocolled treatment as described in the manuscript.

Supplemental Table 2:

Overview of cell characterization results. Donor site A = abdomen, T = thighs. Fat tissue = tissue amount used for ADRC isolation. Fat graft = amount of lipoaspirate used for cell-enriched fat grafting. Cells / g fat was calculated as the number of nucleated cells pr g of fat. CFU-F = Fibroblastoid colony forming units, Surface marker analysis based on flow cytometry. %Stromal stem cells defined as the CD235a-CD45-CD31-CD34+ cell population.

Supplemental Table 3:

Arm heaviness and tension measured on a numerical rating scale from 0-10. DASH: Disabilities of Arm, Shoulder and Hand, LYMQOL: Lymphedema quality of life questionnaire. Excess arm volume measured as the difference in volume between the two arms based on multiple circumference measurements. Excess arm volume DXA: Difference in volume between the two arms based on Dual-energy X-ray absorptiometry. Data shown as either median (ICR) or mean±SD.

*= p<0.05, ** = p<0.01, *** = <0.001. Columns display results at baseline and 1, 3, 6, and 12 months postoperatively respectively.