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Fat Grafting of the Foot for Fat Pad Atrophy –A Review Study

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Abstract

Background: Fat pad atrophy, also known as heel fat pad syndrome, is a common cause of plantar heel pain resulting from thinning of the specialized subcutaneous fat layer on the sole of the foot, leading to reduced shock absorption, pressure distribution, and increased pain during weight-bearing activities. Traditional treatments such as orthotics and dermal filler injections provide symptomatic relief but do not address the underlying volume loss and often require repetition. This paper reviews autologous fat grafting as a regenerative treatment for plantar fat pad atrophy and compares it to alternative therapies.

Methods: The procedure involves harvesting adipose tissue from donor sites (e.g., abdomen or thighs) via liposuction, processing it through sedimentation or centrifugation, and injecting it into atrophied areas of the foot using a crosshatch pattern for even distribution. A case study of an 83-year-old male with longstanding bilateral forefoot pain unresponsive to orthotics is presented, detailing preoperative assessment, surgical technique, postoperative management (including offloading and hyperbaric oxygen therapy), and follow-up outcomes.

Results: The patient experienced minimal postoperative pain, progressive perceived improvement in fat pad volume, reduced sensitivity, and significant pain relief, with increased activity levels sustained at two years post-procedure and no complications reported.

Conclusion: Autologous fat grafting offers a biocompatible, potentially long-lasting solution by restoring natural cushioning and leveraging adipose-derived stem cells for regenerative effects, with the potential to outperform temporary alternatives in addressing the root cause of fat pad atrophy. Further research with larger cohorts and objective volumetric measurements is recommended to validate these findings.

Keywords

Fat Pad Atrophy Heel Fat Pad Syndrome Plantar Heel Pain Autologous Fat Grafting; Adipose-Derived Stem Cells (ADSCs); Foot Cushioning Restoration Regenerative Medicine Plantar Fat Pad Shock Absorption Metatarsalgia Liposuction Harvesting Minimally Invasive Foot Procedure Orthotics Dermal Fillers; Hyperbaric Oxygen Therapy (HBOT); Forefoot Pain Heel Pain Biocompatibility Graft Survival Mesenchvmal Stem Cells.

Introduction

Plantar heel pain (PHP) is reported to affect 1 in 10 people throughout their lifetime [1]. Plantar heel pain can present due to multiple diagnoses, such as, plantar fasciopathy/fasciitis, Heel fat pad syndrome (HFPS), nerve irritation, calcaneal stress fracture, and lumbar radiculopathy [2-4]. HFPS, also known as fat pad atrophy, is a condition which the natural cushioning of fat from the bottom of the foot thins out, which causes pain and discomfort [5]. The plantar fat pad plays a crucial role in foot biomechanics including shock absorption, pressure distribution, protection, and proprioception. The primary role of the plantar fat pads is to absorb impact forces during activities such as running and walking, to avoid excessive stress of bones, joints, and soft tissue [6]. The fat pad can then help distribute pressure across the foot surface to avoid localised areas of high pressure [7]. This means it can then act as protective layer to shield delicate structures within the foot and contribute to the body's ability to sense position and movement [8] Studies suggest that aging, injury, repetitive or prolonged overloading (for example, as seen in endurance runners), obesity, improper footwear, steroid injections, and comorbidities (e.g., diabetes, rheumatic diseases) can negatively affect the structural and functional properties of the heel fat pad [4, 9]. Symptoms for this condition include pain within the heel or ball of the foot specifically when weight bearing, increased sensitivity and tenderness, callus formation, and difficulty walking or standing for extended periods [10].

The purpose of this paper is to review existing treatments of fat pad atrophy, detail the use of autologous fat grafting in a patient case study and suggest future directions to determine the most successful method for fat pad atrophy treatment.

Anatomy and pathophysiology

The plantar fat pad is a specialised subcutaneous tissue layer on the sole of the foot, mostly on the heel and metatarsal head [11]. It is superficial to the plantar aponeurosis and other deeper structures [12]. The plantar fat pad is a complex structure consisting of lobules of adipose tissue separated by strong, elastic connective tissue septa which creates a chambered, honeycomb-like structure, allowing for even distribution of pressure and shock-absorption [13]. The main cellular component are adipocytes, organised into lobules. Collagen and elastic fibres form the septa and are attached to nearby bones and skin, providing resistance to compression and stability. The fat pad is also comprised of nerves and blood vessels, including Pacinian corpuscles, supporting its sensory function [14]. The heel pad is very thick to provide cushioning for the calcaneus against shear and vertical loading whereas the metatarsal pad is

thinner in comparison and protects the metatarsal heads for weight bearing, stabilises the arch and contributes to proprioception for propulsion [15].

The plantar fat pad acts as a mechanical barrier and protects underlying bones and soft tissues from impact forces. The honeycomb-like structure and viscoelastic properties of adipose tissue allow for energy dissipation during weight-bearing, which is essential for activities such as walking, running and jumping [16]. This reduces forces upon the musculoskeletal system, protecting bones and joints [17].

Age contributes to a natural decrease in volume and elasticity of adipose tissue throughout the body. This includes a reduction in adipocyte size and number and the degeneration of the elastic septa [18]. Another contributing factor to fat pad atrophy is the repetitive stress and overload in the heel and metatarsal heads. The chronic mechanical stress of high impact activities or prolonged standing can lead to the damage and breakdown of the fat pad structure resulting in thinning and loss of cushioning capacity [13]. Other factors such as steroid injections and obesity are associated with fat pad atrophy [15]. Similarly, comorbidities such as rheumatoid arthritis or diabetes mellitus are associated with fat pad atrophy due to inflammation, the destruction of soft tissues [19] and microvascular changes and neuropathy [20] respectively.

Review of existing treatments

Treatment for fat pad atrophy often provides symptom relief rather than addressing the root cause. Orthotics or padding are often the first line of treatment as they are non-invasive, and inexpensive, providing pain relief by redistributing pressure [21]. However, they only address the symptoms and not the fat pad loss itself. Some individuals may also find the orthotics to be uncomfortable or bulky [22]. Another treatment option is the injection of dermal fillers, often hyaluronic acid. These fillers are injected within atrophied areas to add volume to the fat pad. This treatment is minimally invasive and can provide immediate relief, however, the effects are reported to be short term, maintained up to six months post-injection [23, 24]. Additionally, rare complications of this procedure can include inflammation, infection, or injection into the blood vessels [25].

Other emerging interventions include Acellular Dermal Matrices (ADM) and Allograft Adipose Matrices (AAM). As these matrices are decellularised, they eliminate the risk of immune rejection commonly associated with allografts and the risk of donor site morbidity. The benefit of ADMs has been demonstrated in breast reconstruction surgery; however, some of these studies suggest an increased complication rate is associated with ADM use, and ADM implantation techniques [26]. Other limitations of ADMs are general surgical risks, limited evidence and the potential for limited volume restoration [27].

AAMs are decellularised human adipose tissues, commonly used for soft tissue volume restoration [28]. They are injectable and are rich in angiogenic and adipogenic matrix proteins such as collagen types I and III, fibronectin and glycosaminoglycans. Whilst these matrices have shown promising effects in small trials, it is not yet completely understood how they interact with infiltrating host cells [29] and, similarly to ADMs, these findings are yet to be supported by large-scale randomised controlled trials [28].

Autologous fat grafting is a relatively simple procedure, as the fat is easy to obtain and can be harvested

repeatedly. Autologous fat is derived from the patient's body, leading to smaller immune reactions and reducing the chance of foreign-body reactions or rejection [30]. Fat tissues are a rich and accessible source of Mesenchymal Stem Cells (MSCs), called Adipose-Derived Stem Cells (ADSCs) when derived from adipose tissue [31]. ADSCs are crucial in tissue repair and regeneration as they secrete growth factors and other bioactive molecules that promote healing and reduce inflammation. In addition to providing cushioning and relieving pain, fat grafting may also increase regenerative potential within the injection area [32]. Early studies have supported the safety and efficacy of this procedure; however, the longevity of its effects remain unclear [15].

Key evidence supporting autologous fat grafting comes from the work of Gusenoff et al., including a prospective randomised clinical trial demonstrating that pedal fat grafting significantly improves pain and disability outcomes while preventing worsening of foot pressures when compared to conservative management [33]. In this study, patients receiving fat grafting showed better foot function, reduced pain, and maintained or improved tissue dynamics at one-year follow-up, with no major complications. Similarly, a study evaluating the outcomes of autologous pedal fat pad grafting 10-years after the procedure showed that the location of the graft has pronounced effects on the results, with heel grafting associated with significant long-term improvements, suggesting that restoration of volume can lead to durable biomechanical benefits [15]. Complementary long-term data and reviews, such as the narrative review by Bcharah et al., further support the use of fat grafting to restore cushioning, alleviate pain, and address the underlying volume loss in pedal fat pad atrophy, outperforming symptomatic treatments in terms of durability and regenerative potential [34].

However, fat graft resorption can be unpredictable and heavily dependent on the technique used and patient characteristics, with reported volume retention spanning from 30-80% [30,35]. Similarly, forefoot grafting is reported to be less durable than heel grafts, perhaps due to its thinner structure and essential roles in daily activities such as propulsion during walking [15]. Additionally, the use of a second graft site can introduce higher chances of complications such as infection, and longer procedure times [28].

Fat grafting technique and patient selection

Patients are evaluated for eligibility which involves a comprehensive assessment to confirm the diagnosis, identify suitable candidates, and mitigate risks. A key eligibility criterion is patients who have tried other treatments for fat pad atrophy symptom relief (e.g., orthotics, pads, shock-absorbing shoes, injections) with little success [36]. The primary material used in autologous fat grafting is the patient's own adipose (fat) tissue, which is harvested from donor sites with excess fat. Common donor areas include the abdomen, flanks, thighs, and belly. No synthetic or foreign materials are typically required, as the procedure relies on autologous tissue to avoid allergic reactions or rejection [37]. Equipment for the procedure includes liposuction cannulas, centrifuge (depending on processing method), and syringes (1 ml for precise injection).

This procedure is performed in a sterile environment with the patient under anaesthesia. The foot/feet to be operated on are then exsanguinated, prepped with betadine and draped. The harvesting area is also prepped with betadine and draped. Prior to harvesting of the fat, local adrenaline is infiltrated. Fat harvesting is then completed using a liposuction cannula, inserting it through small incisions into fatty

areas, moving it in a controlled back-and-forth or vibrating motion to break up fat while sucking the loosened fat cells with a syringe. This is repeated until an adequate amount of fat is harvested. Following liposuction, the entry points of the cannula are then sutured.

The fat then requires processing to remove any excess fluids, blood and debris to maximise the survival of healthy fat cells, minimise inflammation and ensure better graft integration. This can be done by sedimentation or centrifugation. Sedimentation is a method of leaving the collected tissue alone to rest, allowing gravity to naturally separate the components, with the pure fat rising to the top. This is considered a gentler method for the fat cells. Alternatively, centrifugation involves the spinning of the fat at specific speeds to separate the viable fat cells from other components by creating distinct layers for easy harvesting of the pure fat.

Once the fat has been separated and the excess is removed, the fat is ready for injection. The fat is injected into the atrophied areas, often under the metatarsal heads in the forefoot or the heel microchamber, using a crosshatch pattern. This technique distributes the fat evenly in small amounts to prevent large boluses that could lead to cell death or necrosis.

Following injection, there is no need for sutures and patients do not require overnight stay. Pain can be managed with alternating acetaminophen and ibuprofen, avoiding ice to prevent reduced blood flow to the graft. Compression garments can be used for the first 6 weeks to minimise swelling or bruising. For the first 4 weeks post operation patients are recommended to use offload pressure by using a darco shoe with crutches or a knee scooter, allowing partial weight-bearing in the latter half of the 4 weeks. At 4-6 weeks, patients can often weight bear as tolerated in supportive, well-cushioned shoes, but should still avoid high-impact activities. Then by 6-8 weeks patients can typically return to regular footwear and gradually resume higher-impact activities once approved by the surgeon. Low impact activities such as hydrotherapy or a stationary bike can also help accelerate patient recovery and return to regular activity.

Case Study

An 83-year-old man with bilateral foot pain in the ball of his feet for more than 50 years, labelled as neuropathic pain. This had been previously resolved with orthotics, however, is no longer effective. He was able to walk for 2-3km in his shoes where he could do most things with his orthotics, but unable to do anything without. The patient's pain profile at night was reported to be a 1-2 when doing nothing, however, was a 7 after an active day. The final opinion of the author is the patient had bilateral fat pad loss, where nothing will change without the procedure. The fat graft procedure was then completed on the patient with no complications. The patient had 2 pre-load sessions of the HBOT (Hyperbaric Oxygen Therapy) prior to the procedure and 3 sessions after. This protocol was used as HBOT may be able to improve graft survival, enhance tissue integration, and promote healing as it boosts angiogenesis, prevent graft necrosis, reduces inflammation and swelling, and improves longevity [38-40]. The patient wore a darco shoe for each foot, ambulating with support of crutches. One week post operation, the patient felt well with minimal pain. A diabetic sock was suggested to reduce the swelling in operative areas.

After three more weeks, the patient felt further improvement and reported a feeling of fullness at the

graft. The fat pad size increased with the patient feeling confident to trialing weight bearing. The patient instructed to gradually progress off the shoes until the next review. At eight weeks post-op, the patient was still using the shoes, however, could take short unassisted walks. The patient started hydrotherapy sessions to assist in recovery. At twelve weeks post-op, the patient could walk 200 meters per day with the forefoot pad taking shape. To further the recovery process, the patient added the stationary bike to his routine. At ten months post-op, the patient reported that the pain had settled, and an improved fat pad was observed. The patient had significantly increased activity and was satisfied with the outcome of the surgery. No complications have been reported at the finalisation of this paper, two years postoperatively.

Discussion

The findings from this case study align with emerging literature on regenerative approaches to fat pad atrophy, discussed in the review conducted by Bcharah et al., which highlights the efficacy of autologous fat pad grafting for restoring fat pad volume and reducing heel pain compared to temporary solutions like dermal fillers or orthotics [34]. In addition to increased overall volume, an increase in dermal thickness was observed in patients, which was proposed to be due to the regenerative effects of ADSCs or increased trophic support within the tissues. These regenerative effects are supported by other research which suggests that adipose tissue grafting may offer distinct advantages for fat grafting, including biocompatibility and the regenerative potential of adipose-derived stem cells, which promote tissue healing and provide anti-inflammatory effects [31, 32]. The review conducted by Bcharah et al. also reported that pain relief was sustained despite a decrease in plantar tissue thickness observed in the longer term. The researchers suggested that the fat graft may migrate as a softer layer of tissue, suggesting that fat grafts may also improve tissue quality within the fat pad in addition to adding to overall volume. These results demonstrate the multiple benefits that autologous fat grafting could have for patients suffering from fat pad atrophy.

The limitations of this study are the sample size of one, and lack of imaging or use of validated pain scores. Other broader limitations of this technique are the need for surgical expertise, variability in graft survival rates [35], and the absence of long-term, large-scale randomized trials to compare outcomes against alternatives like Acellular Dermal Matrix or Allograft Adipose Matrix. In contrast to non-invasive options that merely alleviate symptoms, fat grafting addresses the underlying volume loss, though it may not be suitable for all patients due to donor site requirements and recovery time. Future research should focus on multicenter studies with volumetric imaging (e.g., MRI) to quantify long-term retention and explore adjunct therapies like hyperbaric oxygen to optimise graft viability.

Conclusion

In summary, this review and case study support the use of autologous fat grafting for addressing fat pad atrophy, through the restoration of plantar fat pad volume, to achieve sustained pain reduction and improved mobility patients. Clinically, this approach represents a promising, minimally invasive alternative to symptomatic treatments like orthotics or fillers, with lower risks of rejection and potential regenerative benefits from ADSCs. Overall, fat grafting holds substantial potential as a sustainable, long-term solution for fat pad atrophy, contributing to the restoration of ideal foot biomechanics, reducing

pain and enhancing quality of life, though further prospective studies are warranted to refine protocols and determine feasibility in a broad range of patients.

Contribution

Contribution	Author
Application of technique (fat grafting)	Dr Gordon Slater
Treated patient with technique	Dr Gordon Slater
Analysed the results of the study	Dr Gordon Slater/ Mr Zadane Bachmid
Writing of the paper	Mr Zadane Bachmid, Toni Worrall
Proofreading/Editing of the paper	Dr Gordon Slater

Disclaimer

Dr. Gordon Slater has a pecuniary interest in Integrant a biotechnology company and Regen U clinics where he actively advises on treatment protocols and implant design.

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