Review

Current concepts in curative surgery for diabetic forefoot ulcers

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ABSTRACT

Forefoot ulcerations in patients with diabetes are quite common. Underlying mechanical deformities of the foot in combination with neuropathy are the most important risk factors for ulcer development and adequate off-loading is the mainstay of management. Most ulcers heal with local wound care, adequate blood supply, and pressure relief. If a foot deformity cannot be accommodated, ulcers will not heal or may recur. In this case, surgical correction of deformity is necessary. This paper reviews the most common procedures supported by medical evidence to heal neuropathic forefoot ulcers.

1. Introduction

The global prevalence of diabetes mellitus is rising. Diabetes mellitus (DM) was estimated to affect approximately 366 million people worldwide in 2011 and experts predict that 552 million individuals will be diagnosed with the disease worldwide by 2030 [1]. DM is a common, complex, and costly disease affecting 9.4% (30.3 million) of Americans. The financial cost of treating diabetic foot ulcerations (DFU) has greatly increased along with the prevalence of DM over the past two decades [2]. In patients with diabetes, there is a lifetime incidence of foot ulcers ranging from 19% to 34% [3]. The peripheral neuropathy in combination with this repetitive trauma causes moderate to high pressure and shear, predisposing the patient to foot ulceration [4]. Plantar foot deformities are often associated with sites of increased pressure such as hammertoes and hallux valgus deformity.

Surgical correction of a structural foot deformity is controversial in this high-risk patient population. Surgical intervention for diabetic foot ulcerations should be considered for patients who have failed proper offloading and wound care, or who have recurrent ulcers with appropriate preventative care if appropriate after proper optimization has been completed. The rationale for surgical intervention is to correct the structural deformity and/or increase motion and interrupt the causal pathway to foot ulceration. Surgical intervention in the diabetic foot can be classified by one of four groups: elective, prophylactic, curative, and emergent. These groups support that there may be opportunities to intervene in the pathway to deformity, ulceration, and infection before amputation becomes the only surgical option. This article discusses the current evidence for elective surgery to treat DFUs to heal and/or prevent future ulcerations.

2. Risks with and without surgery

The surgeon must consider and discuss the risks and benefits of treatment with the patient. First, the risk of a chronic open wound must be discussed. The patient should understand the incidence of soft tissue and bone infection, as well as the high risk of foot or leg amputation. The surgeon must also consider the patient recently diagnosed with diabetes or those who have been well controlled since diagnosis as they may have normal or near normal healing parameters. On the other hand, patients with chronically elevated blood glucose, peripheral neuropathy, peripheral vascular disease, pedal deformities, or end-stage renal disease, or, whose duration of diabetes is greater than 10 years, which correlates with high prevalence of said co-morbidities, have greater risk for complications [5]. Adequate assessment of the patient's neurovascular status and medical condition will give the surgeon an opportunity to discuss their individual risk of surgically treating the condition.

3. Evaluation of the surgical patient

When an ulcer has recurred, or does not heal, surgical care must be considered if the etiology is related to a deformity that causes repetitive stresses on the tissues. There are elements that influence wound healing that can fluctuate (bacterial load, blood glucose levels, and nutritional status, etc.), while others can remain static but unrecognized or underappreciated (deformity, limited joint mobility, anemia, peripheral vascular disease, etc.). All factors must be evaluated and addressed to heal the ulcer and prevent recurrence. When a patient with diabetes presents with a foot wound, the entire patient should be evaluated to

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accurately understand their risk of surgical and nonsurgical treatment. The patient's cardiovascular, neurologic, and renal status should be assessed on initial presentation.

With an aging population and an increasing prevalence of diabetes mellitus, peripheral arterial disease (PAD) will become increasingly more common; therefore, surgeons should have a high index of suspicion when evaluating a patient with diabetes. Other known risk factors for PAD include: male, smoking, increasing age, non-Hispanic Blacks, hypertension, hyperglycemia, dyslipidemia, elevated C-reactive protein, hypercoagulable, hyperhomocysteinemia, and chronic renal insufficiency [6–12]. A standard chemistry, complete blood count, prothrombin time, partial thromboplastin time, creatinine phosphokinase, hemoglobin A1c, erythrocyte sedimentation rate, and lipid profile are useful labs to consider when assessing healing potential and cardiovascular risk preoperatively [11,13].

Assessing perfusion is a primary concern for a surgeon contemplating treatment for a patient with diabetes. A recent history of healing is probably the best indicator of healing potential. A patient that has already proven they can heal a foot ulcer with wound care and offloading has a good prognosis for healing a surgical procedure that reduces the deforming force responsible for the ulcer recurring. First, the peripheral pulses of the lower extremity should be manually palpated: femoral, popliteal, dorsalis pedis, and posterior tibial arteries. A ratio between the systolic pressure in the ankle divided by the systolic pressure of the brachial artery should be obtained (ankle brachial index, ABI) during the workup. An ABI less than 0.9 is an independent risk factor for cardiovascular events including death and increases the patient's risk for complications in wound healing [14]. Several authors have reported successful wound healing rates approaching 90% if the ABI is greater than 0.45 [15,16]. These results were more recently reproduced with an ABI equal to or greater than 0.5 in patients with diabetes [17].

However, caution must be taken in patients with an ABI between 0.5 and 0.9 as this range indicates peripheral vascular disease, and should be treated, if indicated, in patients having elective foot surgery. Patients with diabetes can have a unique pattern of atherosclerosis that causes vascular calcifications that limit the effectiveness of the ABI (Monckeberg's sclerosis). An ABI greater than 1.4 is suspect of this condition and these patients may be at greater risk for cardiovascular events [14]. If peripheral vascular disease is detected, a consult to vascular surgery should be given for more thorough cardiovascular work-up and treatment. A non-invasive vascular exam can often result in normal large vessel perfusion and significant microvascular disease. These patients have a greater risk for a complicated healing course and should be advised of this increased risk and referred to vascular surgery.

Peripheral neuropathy is also a clinical diagnosis that can be made with a focused physical exam. Many detailed clinical exams have been proposed to detect diabetic peripheral neuropathy but have not been used widely in clinical practice because they are time consuming and use expensive equipment [18–21]. Patients who present with ulceration and are considered for surgical interventions and already have neuropathy, and therefore, education about their recovery and lack of painful sensation during the same should be reinforced.

4. Lesser toe procedures

Several authors have reported low infection rates results of elective surgical procedures of lesser toes (4.4–40%). While 40% is quite high, it did not differ from the non-operative group which had a 38% infection rate. Even with a relatively high infection rate, 91–96% of the wounds went on to heal and only 2.4–6.6% of those surgically treated had recurrence of the ulcer [5,22,23].

Armstrong et al. [23] retrospectively examined 31 diabetics and 33 non-diabetic patients who underwent a single lesser digit arthroplasty for hammer toe deformity. This would be considered "prophylactic"

surgery [24]. They further divided the diabetic group into Risk Group 2 (peripheral neuropathy and deformity) and 3 (peripheral neuropathy, deformity, and history of ulcer) [23,25]. They examined postoperative infection rates and dehiscence rates with an average follow up of 3 years. There was a significantly higher risk of postoperative infections in patients who had a previous history of neuropathic ulcerations.

Ulcers of the toes are usually associated with a structural deformity and in many cases are associated with high rates of recurrence [5,26,27]. Toe deformities in patients with diabetes are thought to develop in part due to motor neuropathy that first affects the intrinsic musculature in the foot causing an intrinsic minus foot. One of the purposes of the intrinsic musculature is to stabilize the toes against the metatarsals and so weak intrinsic muscles allow the long flexors and extensors to create an imbalance causing toe contractures. This hammering of the toes may cause pathologic pressure on the distal aspect of the toe, dorsal aspect of the head of the proximal phalanx (from rubbing with the toe box of the shoes), and plantar aspect of the corresponding metatarsal head from ground force when weight bearing. It is crucial to perform a thorough clinical exam of the involved digit(s) in order to plan the appropriate surgical procedure(s). Determining if the deformity is flexible or rigid is critical. The clinical exam, and weight-bearing pedal radiographs are necessary to develop an effective surgical plan.

Ulcers on the tip of the toe are common (Fig. 1). If the long flexor tendons overpower the intrinsics, a flexion deformity can occur at the DIPJ level, placing the normally distal-facing end of the toe in a plantarflexory position, taking up pathologic pressure. The distal tip of the toe has little fat to absorb the shock and shear of standing, walking, and running. The increased pressure results in excessive hyperkeratotic build-up, which exacerbates the pathologic pressure on the distal toe. This commonly results in soft tissue infection and direct extension osteomyelitis of the distal phalanx. If regular debridement and offloading (toe crest pads, shock attenuating insole materials, casting, etc.) do not resolve the ulcer or the ulcer recurs, and the deformity is reducible, then surgical release of the long flexor should be considered when

Fig. 1. Ulcer in the distal tip of a lesser toe secondary to a clawtoe.

deformity are flexible or semi flexible [28,29].

Several studies have been conducted with positive results. Laborde retrospectively evaluated 28 toe ulcers that were treated with a percutaneous flexor tenotomy with at least 20 months of follow-up. Seventeen (61%) of the toes with ulceration were the great toe with the remaining being of lesser toes. All of the deformities were manually reducible and all 28 ulcers healed in two months or less [29].

Kearney et al. retrospectively reviewed a cohort of 48 patients with 58 FHL tenotomy procedures with diabetes related neuropathic ulceration at the tip of the toe [30]. Almost all ulcerations healed (98.3%) at approximately 5 weeks. 12.1% had a recurrence of ulceration at the same site at a mean time of 13.9 months. Tamir retrospectively assessed the results of flexor tenotomy and hyperextension of rigid joint (osteoclasis) in 34 toes (14 patients with diabetes). Twenty-four (71%) digits had a concomitant ulceration at the time of tenotomy. The other digits had a claw toe deformity and had the tenotomy performed prophylactically. They concluded that this procedure is effective for healing wounds penetrating to bone with osteomyelitis (with appropriate antibiotic therapy) but the wound healing will be prolonged [28].

Finally, a recent systematic review of percutaneous flexor tenotomies by Bonanno and Gillies was completed in 2017 [31]. Six studies had 264 flexor tenotomies that were performed on toes with ulcers and 57 performed as a prophylactic procedure. The mean duration of preoperative ulceration was 207.9 (range 7–1825) days. The mean duration to postoperative ulcer healing was 29.5 days, with an overall healing rate of 97%. The results of this systematic review concluded that flexor tenotomy is safe and effective, but prospective studies are still needed. Two other systematic reviews in flexor tenotomies has been published with similar recommendations [32].

Neuropathic ulcers may occur at the dorsal aspect of the proximal or distal interphalangeal joint (Fig. 2) when a flexion deformity is present. When there is a rigid deformity, resecting the head of the phalanx is usually necessary and the procedure can be performed at the proximal or distal interphalangeal joint depending on where the deformity lies. If there is accompanying soft tissue contracture at the metatarsophalangeal joint, additional procedures may be required to reduce these deformities.

Only two retrospective studies that report outcomes and complications of arthroplasties in persons with diabetes were identified. Armstrong et al. evaluated a cohort of patients with arthroplasty of the proximal interphalangeal joint for hammer toe deformity and stratified them by the presence of diabetes (31 with diabetes and 33 without diabetes). The authors found that 14.3% of patients who had diabetes and a history of ulceration had a postoperative infection. Ultimately

Fig. 2. Ulcer dorsal aspect of proximal interphalangeal joint of fifth toe. This ulcer often needs resectioanl arthoplasty of the proximal interphalangeal joint of the toe.

Fig. 3. Hallux flexus is a common deformity that leads to ulcer in the dorsum or distal aspect of the hallux. The deformity can be corrected with arthroplasty of arthrodesis of the interphalangeal joint.

96.3% of these patients went on to heal the ulcer and remained ulcer free for at least 12 months [23].

Kim et al. reported results of a cohort of patients with diabetes with ulcers and osteomyelitis. They reviewed 72 lesser toe arthroplasties performed because of ulceration and underlying osteomyelitis. They removed devitalized tissue and infected bone with 79% of the toes completely healing in 32 days [33]. Both studies show how an arthroplasty at the site of the deformity is effective at reducing the deformity with favorable healing rates (96% for wounds without osteomyelitis and 79% for wounds with osteomyelitis).

5. Great toe procedures

Greater than half of plantar foot ulcers occur either on the hallux or the first metatarsal head [34,35]. Given this, ulcers at these locations have been the topic of much discussion with surgical correction has been controversial [22,23,36,37]. Distal hallux ulcerations usually occur secondary to a flexion deformity at the interphalangeal joint which causes excessive pressure on the distal aspect of the hallux (Fig. 3) [38]. This deformity should be classified as either rigid or flexible. A flexible deformity can be treated with a flexor tenotomy but rigid deformities should be addressed with an interphalangeal joint arthroplasty (IPJ) [29]. In a retrospective study, Lew et al. compared healing outcomes between hallux IPJ arthroplasty group (n = 13), and a non-surgical group (n = 13) with a mean follow-up duration of 19.5 (range 1.2–47.9) months. The median time to healing was 9 weeks in the standard therapy group and 3.5 weeks in the surgical group with a recurrent hallux ulceration rate of 7.7% (1 of 13) in the surgical group and 53.9% (7 of 13) in the standard therapy group. The incidence of amputation was 0% (0 of 13) in the surgical group and 38.5% (5 of 13) in the standard therapy group and concluded that hallux IPJ arthroplasty is effective and safe to heal hallux IPJ ulcerations [39].

An ulcer that occurs strictly at the plantar aspect of the hallux interphalangeal joint with adequate first metatarsophalangeal joint range of motion should alert the clinician to the possibility of an accessory sesamoid (Fig. 4). This diagnosis requires a close inspection of the appropriate radiographs. Surgical removal of the sesamoid could effectively decrease the pressure and lead to wound healing but there is no published data on the long-term outcomes of this isolated procedure in patients with diabetes.

Structural deformity with limited joint mobility of the first metatarsophalangeal joint is often associated with ulcers under the metatarsal head and interphalangeal joint of the great toe (Fig. 5). Hallux

Fig. 4. An interphalangeal joint sesamoid may be seen on radiographs when a plantar hallux ulcer is present. Excision of the sesamoid might be a surgical option.

Fig. 5. Neuropathic ulcer in the plantar medial aspect of interphalangeal joint of the hallux. Hallux limitus is the most common cause of ulcers in this location.

Fig. 6. Plantar ulceration healed after resection of base of proximal phalanx of the hallux (Keller arthroplasty). Noticed the shortened proximal phalanx of the hallux.

rigidus and hallux valgus can present individually or combined. Both lead to force imbalances about the first metatarsal phalangeal joint and hallux. Arthroplasty of the base of the proximal phalanx of the great toe (Keller arthroplasty) is the most common procedure described (Fig. 6). The surgical options to heal and prevent recurrence include arthroplasty of the interphalangeal joint of the great toe, metatarsophalangeal joint arthroplasty, or metatarsophalangeal joint arthroplasty with implant (total or hemi-implant). Keller arthroplasty is a procedure that improves the motion and alignment of the first metatarsophalangeal joint by removing the proximal aspect of the proximal phalanx of the hallux. One of the most important technical aspects of the procedure is to maintain the insertion of the flexor hallucis brevis (FHB) tendon which can be accomplished with a limited resection of the base of the proximal phalanx [40].

Few studies have been published looking at the effectiveness of arthroplasty of the 1st metatarsophalangeal joint. Stewart reported that patients with diabetes were four times more likely to have the base of the proximal phalanx of the hallux resected than a metatarsophalangeal joint arthrodesis or implant arthroplasty [41]. Lin et al. reported that fourteen recalcitrant plantar hallux wounds healed in twenty-three days or less after resecting the base of the proximal phalanx of the hallux and off-loading in a total contact cast compared to fifteen randomly selected controls. All of the surgical candidates had toe-brachial indices of at least 0.65 and initially failed 40 days of total contact cast therapy before surgery. All of the controls healed in an average of 47 days with

total contact cast immobilization. There were no recurrences or other complications 26 weeks after surgery [42].

Downs reported six cases of recalcitrant plantar hallux wounds that healed with resection of the base of the proximal phalanx, all of which failed non-operative treatment. This case-series had a 100% healing rate after vascular status was improved/declared adequate for healing per a vascular surgeon. One of the six had delayed surgical wound healing that went on to complete healing with local wound care. One patient had a second lesion at the distal aspect of the second toe of the ipsilateral foot that required a partial amputation of this toe that healed uneventfully. There were no other complications documented with at least two years of follow-up [43,44]. In a case control model, Armstrong et al. evaluated 41 patients with ulcers classified as University of Texas Grade 1A or 2A at the plantar aspect of the hallux interphalangeal joint. Patients were treated with resection arthroplasty of the 1st proximal phalanx base and control subjects received standard nonsurgical care. The surgery group healed significantly faster than patients in the standard therapy group (24.2 ± 9.9 vs 67.1 ± 17.1 days respectively) and they had fewer re-ulcerations (4.8% vs 35.0% respectively). Both groups had similar rates of infection (standard 38.1% vs surgery 40.0%), amputation (standard 10.0% vs surgery 4.8%), and there was no difference between the 2 groups with respect of infection or amputation [44]. The authors believe that resection of the base of the proximal phalanx of the hallux improves motion at the 1st metatarsophalangeal joint and the true effect on ulcer healing may be the resultant lack of purchase from the shortened hallux instead of the increase motion at the joint.

6. Metatarsal procedures

Ulcerations occur due to focal plantar pressure from a prominent or deformed metatarsal as well as ankle joint equinus that could contribute to the deformities in the forefoot (see equinus section below). This must be thoroughly evaluated both clinically and radiographically to determine the etiology and effective surgical intervention. The causes of such ulcers are often due to the following deformities: hammer-toe, hallux valgus, forefoot arthropathy, soft tissue atrophy, compensated or uncompensated forefoot varus or valgus [45,46].

Surgeons have performed isolated metatarsal surgery at the apex of the deformity [47], however, some have advocated for removal of all metatarsal heads (Fig. 7) because of a relatively high rate of peak pressure being transferred to an adjacent metatarsal head and causing a secondary ulceration. One study demonstrated that if less than 25% of the metatarsal head is resected, it will lead to recurrence [48]. In our experience, a single metatarsal head resection can be successfully done in patients with flexible deformities in combination with adequate shoe gear.

Successful ulcer healing has been demonstrated in several studies. Blume conducted a retrospective study of 67 diabetic patients that had peripheral neuropathy and an ulcer without osteomyelitis. All patients underwent a single-stage osseous procedure (arthroplasty, exostectomy, phalangectomy, planing, etc.) of the forefoot, midfoot, or rearfoot with primary closure with local flaps. Ultimately, 97% of the ulcers healed after surgery and 96% were healed 20 weeks after surgery [49].

Rosenblum excised 22 metatarsal heads, performed 15 metatarsal osteotomies, and 5 panmetatarsal head resections in 42 feet that had recently undergone lower extremity revascularization procedures. Eighty-three percent (35/42) healed primarily and maintained an ulcer free foot along with patent bypass grafts during the 21 months follow-up period. Ultimately, forty (95%) went on to heal with no recurrence in the follow-up period [50]. Giurini et al. retrospectively analyzed 34 panmetatarsal head resections in patients with diabetes and a forefoot ulcer [51]. Thirty-two feet healed primarily, one healed slowly with secondary intention and one had a recurrent ulcer. Ultimately, 97% of the ulcers healed and remained ulcer free for an average of 20.9 months. At short term follow up, the studies demonstrate that intrinsic

Fig. 7. In a rigid foot, a panmetatarsal head resection may be a choice to heal an ulcer. Shoe modification is required for prevention of re-ulceration.

pressure relief of metatarsal head procedures are successful in healing ulcers. In a case-control model, Armstrong et al. evaluated 92 patients with diabetes with ulcers classified as University of Texas grade 1A or 2A at the plantar aspect of the forefoot at 1 year follow-up [52]. Patients in the surgery group healed significantly faster than those in the standard therapy group (84.2 days control vs. 60.1 days surgery group) and had fewer re-ulcerations (39.1% control vs. 15.2% surgery group). There was no significant difference in the proportion of patients receiving an incident amputation in the follow-up period.

7. Addressing equinus

Equinus deformity of the ankle has been associated with increased pressures on the plantar aspect of the forefoot and increased risk of ulcerations in persons with diabetes [53]. For instance, diabetic patients with equinus were three times more likely to have elevated forefoot pressures compared to diabetic patients without equinus [53,54]. Ankle joint equinus deformity has been defined in different ways from, "a plantarflexed sagittal plane attitude of foot to leg with maximum ankle joint dorsiflexion" to, less than 15° of "normal" dorsiflexion [55–57].

Grant et al. reported that the structure of the Achilles tendon was

distorted in patients with diabetes compared to persons without diabetes using electron microscopy. The authors identified increased packing density of collagen fibrils, decreased fibrillar diameter, and abnormal fibril morphology [58]. A recent study reported Achilles tendinopathy by ultrasound in 89% of patients with diabetes mellitus [59]. Advanced glycation-end products have been suggested to alter the biomechanical properties of soft tissues, resulting in stiffness and reduced flexibility [60]. Reddy demonstrated that tendon glycation contributes to abnormal biomechanical properties by increasing tensile strength, Young's modulus of elasticity, energy absorption, and toughness in an in vitro study with Achilles tendons in New Zealand white rabbits [61]. If this same process occurs in humans with diabetes, advanced glycation end-products could shorten and stiffen the Achilles tendon. During gait, this would reduce the time of heel strike and subsequently increase the duration of midfoot and forefoot loading, increasing peak foot pressures in the forefoot.

7.1. Achilles tendon lengthening

To address this deformity in patients with recalcitrant forefoot ulcers, several authors have surgically lengthened the Achilles tendon (ATL). The most common procedure described in the medical literature in patients with diabetes is a percutaneous lengthening of the Achilles tendon (Fig. 8). Percutaneous ATL is simple to perform and can be done with local anesthesia. Many patients that would be considered for the procedure have severe neuropathy and the regional pain during the procedure is obscured by neuropathy. This is accomplished by small stab incisions on the posterior aspect of the leg, so it is uncommon to have difficulty healing these incisions. It is crucial to determine the etiology of the ankle joint equinus deformity because; it may be due to osteoarthritis. If the equinus etiology is osseous, the ATL will not work and will require the osseous deformity to be addressed. Holstein

Fig. 8. Percutaneous Achille's tendon lengthening can assist in forefoot ulcer healing or prevent recurrence by decreasing peak plantar pressure.

observed 47% of his patients that met the criteria of complete lack of sensation at the heel, developed heel ulcers postoperatively [62], in which 14% of those occur on those with excessive ankle dorsiflexion (> 15°).

The ATL procedure has a growing body of evidence that supports its clinical effectiveness and documents potential complications. Mueller and colleagues performed the only randomized clinical trial assessing the effectiveness of ATL versus a total-contact cast control in healing diabetic foot ulcers [54]. The criterion for surgery was ankle dorsiflexion less than 5°, recurrent or non-healing Wagner grade II ulceration, palpable ankle pulse, and neuropathy. All of the ATL patients healed in an average of 58 ± 47 days and 88% healed in a mean time of 41 ± 28 days in the total contact cast group. Average ankle joint dorsiflexion increased 15.2° with the knee extended in the ATL group and patients maintained this motion at their seven-month follow-up visit. There was no change in ankle range of motion in subjects treated with casting. Patients with an ATL have fewer recurrent foot ulcers compared to controls. Armstrong et al. reported a 27% reduction in forefoot pressures in ten patients with diabetes and a healed foot ulcer after ATL [63]. The average increase in ankle dorsiflexion was 9°. This reduced forefoot pressure helps explain the higher rates of diabetic foot ulcer healing and lower rates of re-ulceration after an ATL compared to off-loading with total contact casts and accommodative shoe gear.

However, an ATL is not without its complications. In addition to the completely neuropathic patients mentioned above, Holstein et al. reported that 18% of patients with more than 10° of ankle dorsiflexion after surgery developed a heel ulcer [62]. Barry and Mueller report heel ulcers in 16% and 13% of patients after undergoing an Achilles tendon lengthening procedure [54,64]. This has been attributed to over-lengthening the Achilles tendon; however, in Mueller's study none of the patients who developed a heel ulcer had excessive motion (9–12° of dorsiflexion) [54].

La Fontaine et al. retrospectively reviewed 28 subjects for new and recurrent ulcers who had an ATL and a transmetatarsal amputation. Results demonstrated that of the 28 patients in which ATL was performed, 16 developed new neuropathic ulcers (including 10 recurrent ulcers; p = 0.009). They concluded high recurrence and new ulcers formation exist after TAL in patients and suggested that extrinsic/intrinsic factors may need to be addressed to prevent recurrence [65].

Postoperative care is critical to minimize these complications. If a neuropathic patient is not compliant with non-weight bearing or protected weight bearing, they can tear or rupture the Achilles and cause over-lengthening. Immobilization in a total contact cast after Achilles tendon lengthening accomplishes several important goals. It reduces patient activity and it forces them to be compliant with off-loading. Crutches, walkers, and wheelchairs should be encouraged after surgery to assist appropriate healing of the Achilles tendon and the ulcer.

7.2. Gastrocnemius recession

Some surgeons advocate that a gastrocnemius recession could be an option to treat forefoot ulcer with the purpose of preventing over lengthening of the Achille's tendon (Fig. 9). We found only 2 articles that look at gastrocnemius recession for plantar diabetic forefoot ulcers. Van Bael and co-workers investigated 7 patients who underwent gastrocnemius recession under local anesthesia for plantar forefoot ulcers. Six of the 7 patients healed in 30 days with the 7th patient healing in 34 days. Improvement on dorsiflexion from preoperative to postoperative dorsiflexion was 10.5°. No major complications or recurrence were observed, but no long-term follow-up was documented [66]. Laborde used the gastrocnemius recession 11 patients with diabetic midfoot ulcers at a follow-up of 39 months. One ulcer did not heal, and one ulcer recurred but healed again after midfoot fusion. There were no incision problems, or transfer ulcers [29].

Fig. 9. The recession is performed at the level of the medial and lateral head of gastrocnemius muscle and only the muscle fascia is released.

8. Conclusion

Diabetic foot ulceration is the leading cause of major amputation in the developed world. Plantar neuropathic ulcers at the forefoot should be managed conservatively with off-loading, but outcomes vary depending on type of offloading, patient's activity, patient's compliance, vascular disease, and diabetes control, among many other relevant variables. With adequate preoperative evaluation, curative surgery can be performed with the properly identified patient. There is evidence to support adequate efficacy of many types of surgical procedures. While there is evidence, the majority of the studied are retrospective without a large body of strong prospective studies.

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