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ANATOMICAL CONSIDERATIONS IN RECONSTRUCTIVE OPTIONS FOR THE ANKLE AND FOOT

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ABSTRACT

BACKGROUND

Soft tissue reconstruction of the foot and ankle is complex due to limited soft tissue availability, unique anatomical constraints, and high mechanical demands. These regions are prone to injuries and chronic wounds owing to trauma, infection, ischemia, and systemic conditions like diabetes. A deep anatomical understanding-encompassing embryology, vascular supply, fascial compartments, and muscular structure-is essential to guide appropriate reconstructive strategies, reduce complications, and improve functional outcomes.

METHODS

This retrospective study was conducted at the Department of Plastic Surgery, RGSSH (Rajiv Gandhi Super Speciality Hospital), RIMS (Raichur Institute of Medical Sciences), Raichur, from January 2021 to December 2024. A total of 71 patients with soft tissue defects in the ankle region were included. The selection criteria focused on defects unsuitable for primary closure and requiring flap coverage. A detailed assessment of each case was done with clinical history, imaging, and intraoperative findings. Operative decisions were made based on anatomical location, exposure of critical structures (bone, tendon, vessels), and patient-specific considerations. Various local, regional, and free flap options were utilized. Postoperative outcomes were evaluated in terms of aesthetic appearance, complication rate, and functional rehabilitation over follow-up.

RESULTS

Trauma was the predominant cause of ankle and foot defects. The posterior ankle and lower third of the leg were the most common locations. The most frequently used flaps included the reverse sural artery flap, medial plantar flap, and extensor digitorum brevis muscle flap, while free tissue transfers were reserved for large or complex defects. Complications included partial flap necrosis, donor site issues, and flap bulkiness. Functional outcomes were satisfactory in the majority, with most patients regaining stable ambulation. Anatomical knowledge played a critical role in selecting and executing appropriate reconstruction techniques, ensuring flap viability and minimizing morbidity.

CONCLUSION

Successful reconstruction of ankle and foot defects necessitates a thorough understanding of regional anatomy and a multidisciplinary approach. Anatomical insights significantly enhance surgical planning, facilitate optimal flap selection, and improve both functional and aesthetic outcomes.

Adapting to the reconstructive elevator model rather than the traditional ladder enables surgeons to achieve superior limb salvage in complex cases.

KEYWORDS: Foot and Ankle Reconstruction, Anatomical Flap Planning, Reverse Sural Flap, Medial Plantar Flap, Soft Tissue Defects, Reconstructive Elevator, Microsurgery, Limb Salvage.

INTRODUCTION

Reconstructive surgery of the ankle and foot presents unique challenges due to the region's complex structural anatomy, high functional demands, and limited soft tissue envelope. The ankle acts as the transitional zone between the vertical leg and horizontal foot, bearing significant load during ambulation, with the average individual taking over 10,000 steps daily. The specialized plantar tissues, although adapted for repeated mechanical stress, are still vulnerable to trauma, ischemia, infection, and systemic conditions such as diabetes, leading to soft tissue breakdown and chronic wounds.[1]

Successful reconstruction requires a nuanced understanding of the region's embryology, skeletal architecture, fascial compartments, neurovascular supply, and muscular anatomy. The vascular supply, derived from the anterior tibial, posterior tibial, and peroneal arteries, supports various local and regional flaps, which must be selected with precision to avoid complications such as flap necrosis or donor site morbidity. Key anatomical structures like the extensor retinaculum, flexor retinaculum, and the plantar fascia play crucial roles in biomechanical stability and influence flap design and placement.[2,3]

Historically, the concept of the "reconstructive ladder" guided flap selection by encouraging surgeons to progress from simpler to more complex procedures. However, with advancements in microsurgery, perforator flap techniques, and greater anatomical insight, the "reconstructive elevator" has emerged as a more pragmatic approach allowing surgeons to directly choose the method that provides the best functional and aesthetic outcome without adhering to a rigid sequence.[4,5]

In complex reconstructions-such as those involving exposure of bone, tendons, or joints-regional options like the reverse sural flap, medial plantar artery flap, and extensor digitorum brevis muscle flap are commonly employed. For extensive defects, particularly those resulting from trauma, osteomyelitis, or malignancy, free tissue transfers such as the ALT (Anterolateral Thigh) flap offer durable coverage and versatility with minimal donor site morbidity.[6,7]

This study explores the anatomical underpinnings critical to flap planning and execution for ankle and foot defects and emphasizes the importance of anatomical considerations in enhancing reconstructive success.

Aims and Objectives

The aim of this study was to evaluate the anatomical considerations relevant to reconstructive options for the ankle and foot by analyzing the incidence, natural history, and clinical presentation of patients with soft tissue defects in the ankle region. It further aims to assess post-debridement or resection defects, explore the types and suitability of flaps available for reconstruction in each case, and identify associated complications-both early and late. Additionally, the study seeks to evaluate the outcomes of flap reconstruction with respect to aesthetic appearance and functional rehabilitation, thereby guiding optimal reconstructive planning based on anatomical and clinical parameters.

MATERIALS AND METHODS

Study Design

This retrospective study was conducted at the Department of Plastic Surgery, RGSSH (Rajiv Gandhi Super Speciality Hospital), RIMS (Raichur Institute of Medical Sciences), Raichur, from January 2021 to December 2024. The study was carried out in the Department of Plastic Surgery at RGSSH and RIMS, Raichur. Patients were selected based on predefined inclusion and exclusion criteria, with the aim of evaluating anatomical considerations and reconstructive options for ankle and foot defects.

Inclusion and Exclusion Criteria

This study included patients with soft tissue defects involving the lower third of the leg, ankle joint, heel, or dorsum of the foot where primary skin closure was not possible, particularly those with exposed bone (with or without fracture), tendon, or vascular structures requiring flap coverage. Only patients who provided valid informed written consent were enrolled. Excluded from the study were patients whose defects were amenable to primary closure, those treated with skin grafts or healing by secondary intention, and patients deemed high-risk for anesthesia.

Data Collection Procedure

Data for the study were collected through detailed clinical history focusing on the mode of onset and progression of the soft tissue defects, followed by thorough clinical examination to identify risk factors and confirm diagnosis. Necessary investigations available at RGSSH and RIMS were performed to support diagnosis and surgical planning. Each patient underwent a pre-operative planning session, where clinical condition and investigation findings were reviewed to finalize the surgical approach. Surgical management was carried out based on these assessments, and post-operative recovery, including any complications, was closely monitored. Patients were regularly followed up in the plastic surgery OPD, and final outcomes were evaluated with respect to both aesthetic appearance and functional rehabilitation.

Statistical Analysis

In this study, descriptive statistical analysis was performed to evaluate the data related to anatomical considerations in reconstructive options for the ankle and foot. Continuous variables were presented as mean ± standard deviation (min–max), while categorical variables were expressed as numbers and percentages. Statistical significance was assessed at the 5% level. The Student's t-test (two-tailed, independent) was used to compare continuous variables between two groups, while chi-square and Fisher's exact tests were applied to assess the significance of categorical variables across groups. Statistical interpretation of p-values was categorized as suggestive significance ($0.05 < p < 0.10$), moderate significance ($0.01 < p \leq 0.05$), and strong significance ($p \leq 0.01$). Data analysis was conducted using SPSS 15.0, Stata 8.0, MedCalc 9.0.1, and Systat 11.0, with Microsoft Word and Excel used for generating graphs and tables.

RESULTS

Wound Location	Frequency	Percentage	Male (%)	Female (%)	Mean Age (in years)
Ankle Posterior	36	50.7%	21 (58.3%)	15 (41.7%)	35.6
Medial Malleolus	10	14.1%	6 (60.0%)	4 (40.0%)	38.2
Heel	8	11.3%	4 (50.0%)	4 (50.0%)	39.5
Ankle Anterior	6	8.5%	3 (50.0%)	3 (50.0%)	34.3
Sole of Foot	4	5.6%	3 (75.0%)	1 (25.0%)	33.8
Dorsum Foot	3	4.2%	2 (66.7%)	1 (33.3%)	30.7
Lateral Malleolus	3	4.2%	2 (66.7%)	1 (33.3%)	34.0
Lower 1/3 Tibia	1	1.4%	0 (0.0%)	1 (100.0%)	42.0
Total	71	100.0%	41 (57.7%)	30 (42.3%)	36.2

Table 1: Distribution of Wound Location and Demographics

Table 1 breaks down the anatomical distribution of defects with demographic correlations. The posterior ankle region was the most vulnerable area (50.7% of cases), with males more frequently affected than females across most sites. The mean age of 36.2 years indicates these injuries primarily affect young, active individuals.

Exposed Structure	Frequency	Percentage	Preferred Flap Types	Mean Hospital Stay (in days)
Tendoachilles (TA)	32	45.1%	Reverse Sural Artery, Propeller	10.0 ± 3.50
Exposed Bone	13	18.3%	Free Flap, Medial Perforator	24.8 ± 3.12
Exposed Tendon	10	14.1%	Propeller, Lateral Perforator	8.9 ± 2.35
Heel Pad Loss	9	12.7%	Medial Plantar Artery	10.2 ± 3.80
Exposed Plate	4	5.6%	Free Flap, Propeller	24.8 ± 3.12
Loss of Sole	3	4.2%	Medial Plantar Artery	10.2 ± 3.80
Total	71	100.0%	-	-

Table 2: Anatomical Structures Requiring Coverage and Reconstruction Options

In Table 2, exposed tendoachilles was the most common reconstructive indication (45.1%), demonstrating its vulnerability to trauma. The choice of flap was clearly influenced by the specific structure requiring coverage, with hospital stays varying significantly based on anatomical complexity.

Cause of Defect	Frequency	Percentage	Most Common Location	Common Exposed Structures
Trauma (Fall)	29	40.8%	Ankle Posterior	Tendoachilles, Bone
Trauma (RTA)	25	35.2%	Ankle Posterior	Tendoachilles, Bone
Diabetic Foot Ulcer	8	11.3%	Sole, Heel	Tendons, Loss of sole
Chronic Osteomyelitis	7	9.9%	Medial Malleolus	Bone
Malignancy	2	2.8%	Dorsum Foot	Tendons, Bone
Total	71	100.0%	-	-

Table 3: Etiology of Defects and Anatomical Considerations

Table 3 shows trauma (76% combined) predominantly affected the posterior ankle, while diabetic foot ulcers (11.3%) typically affected weight-bearing areas. Each etiology showed specific patterns of anatomical involvement requiring tailored approaches.

Anatomical Region	Most Common Flap	Second Choice	Free Flap Usage (%)	Functional Outcome (Good %)
Ankle Posterior	Reverse Sural Artery	Propeller	5.6%	75.0%
Medial Malleolus	Medial Perforator plus	Propeller	10.0%	70.0%
Heel	Medial Plantar Artery	Lateral Calcaneal	12.5%	62.5%
Ankle Anterior	Propeller	Free Flap	33.3%	66.7%
Sole of Foot	Medial Plantar Artery	Medialis Pedis	0.0%	75.0%
Dorsum Foot	Free Flap	Medialis Pedis	66.7%	66.7%
Lateral Malleolus	Lateral Perforator plus	Propeller	0.0%	100.0%
Lower 1/3 Tibia	Free Flap	-	100.0%	100.0%

Table 4: Flap Selection Based on Anatomical Region

Table 4 reveals how surgeons matched flap types to specific anatomical regions. Posterior ankle defects were most effectively managed with reverse sural artery flaps, while the dorsum foot often required free flaps. Functional outcomes varied by region, with lateral malleolus reconstructions achieving the best results.

Flap Type	Frequency	Percentage	Common Locations	Aesthetic Outcome (Good %)	Functional Outcome (Good %)
Peninsular	36	50.7%	Ankle Posterior, Heel	88.9%	77.8%
Island	28	39.4%	Medial Malleolus, Sole	85.7%	71.4%
Free	7	9.9%	Dorsum Foot, Lower 1/3 Tibia	85.7%	57.1%
Total	71	100.0%	-	87.3%	73.2%

Table 5: Anatomical Considerations in Flap Selection and Outcomes

Peninsular flaps (50.7%) were preferred for posterior ankle and heel defects, with excellent aesthetic and functional outcomes. Free flaps had good aesthetic results but lower functional outcomes, reflecting the complexity of cases requiring microvascular reconstruction.

Anatomical Region	Early Complications (%)	Late Complications (%)	Common Complications	Secondary Procedures (%)
Ankle Posterior	13.9%	41.7%	Bulky Flap, Joint Stiffness	19.4%
Medial Malleolus	10.0%	40.0%	Bulky Flap	20.0%
Heel	12.5%	37.5%	Recurrent Ulceration	25.0%
Ankle Anterior	16.7%	33.3%	Joint Stiffness	16.7%
Sole of Foot	0.0%	25.0%	Recurrent Ulceration	25.0%
Dorsum Foot	33.3%	33.3%	Bulky Flap	33.3%
Lateral Malleolus	0.0%	33.3%	Bulky Flap	0.0%
Lower 1/3 Tibia	0.0%	0.0%	None	0.0%

Table 6: Complications Related to Anatomical Regions

Table shows the complication patterns varied by anatomical site. The dorsum of the foot had the highest early complication rate (33.3%), while weight-bearing areas experienced recurrent ulceration. Joint stiffness was common in ankle reconstructions.

Patient Factor	Prevalence (%)	Complicated Cases (%)	Good Functional Outcome (%)	Mean Hospital Stay (in days)
Tobacco Use	54.9%	38.5%	66.7%	12.8
No Tobacco Use	45.1%	21.9%	81.3%	9.6
Diabetes Mellitus	11.3%	50.0%	50.0%	14.3
No Diabetes	88.7%	28.6%	76.2%	10.8
Age <40 years	56.4%	25.0%	80.0%	10.2
Age ≥40 years	43.6%	41.9%	64.5%	12.6
Traumatic Cause	76.0%	29.6%	75.9%	10.9
Non-Traumatic Cause	24.0%	35.3%	64.7%	12.4

Table 7: Impact of Patient Factors on Anatomical Reconstruction Outcomes

Patient factors significantly influenced reconstruction success. Tobacco use and diabetes increased complication rates and reduced good functional outcomes. Advanced age was associated with higher complications and longer hospital stays.

DISCUSSION

The ankle and foot present unique challenges in soft tissue reconstruction due to their complex anatomy, characterized by limited soft tissue coverage, a tenuous blood supply, and critical biomechanical structures such as the tendoachilles and heel pad. In a study of 71 cases of soft tissue defects around the ankle at RGSSH and RIMS, Raichur, anatomical considerations significantly influenced reconstructive strategies and outcomes. The posterior ankle, particularly the region exposing the tendoachilles, was the most common site of defects (50% of cases), underscoring the anatomical vulnerability of this area due to its thin skin and poor vascularity. The reconstructive ladder, progressing from local transposition flaps to free flaps, was employed to address these defects, with flap selection guided by anatomical factors such as vascular pedicles and tissue availability.[5,8]

Anatomically, the ankle and foot have a limited subcutaneous layer, making them prone to exposure of tendons, bones, and joints following trauma, which was the primary cause of defects in the study, predominantly due to road traffic accidents.[9,10] The choice of flap was dictated by the need to match the defect's anatomical requirements, such as replacing like-with-like tissue for the weight-bearing heel or providing robust coverage for exposed tendons.[11] Local transposition flaps, used in 18.3% of cases, were favored for smaller defects due to their proximity and ability to utilize nearby skin with similar texture and vascularity.[12] However, their use is limited by the ankle's restricted tissue mobility and the risk of compromising local blood supply, particularly in the posterior ankle where perforators are sparse.[13]

For larger or more complex defects, perforator-based flaps, such as those based on the posterior tibial or peroneal arteries, were employed, leveraging the angiosome concept to ensure reliable vascular supply.[13] The reverse sural artery flap, used in 13 cases, is particularly suited for posterior ankle defects due to its anatomical alignment with the sural nerve and accompanying vessels, providing robust coverage without sacrificing major arteries.[14] Free flaps, utilized in six cases, were reserved for severe injuries with extensive tissue loss, where local options were inadequate.[15] The anatomical complexity of free flap reconstruction necessitates meticulous preoperative planning, including color Doppler studies to map perforators and confirm vascular integrity, performed in 24% of cases.[16] The dorsalis pedis or posterior tibial arteries were commonly used for anastomosis, reflecting their anatomical accessibility and reliability in the distal lower limb.

Anatomical challenges also contributed to complications observed in the study. Venous congestion (4.2%) and arterial insufficiency (1 case) were early complications, likely due to the ankle's limited venous drainage and the technical difficulty of achieving patent anastomosis in a region with small-caliber vessels.[12] Late complications, such as bulky flaps (22.5%) and ankle joint stiffness (8.4%), reflect the anatomical mismatch between donor tissue and the ankle's thin, pliable skin, as well as the restricted mobility of the ankle joint post-reconstruction. These findings align with studies emphasizing the importance of tailoring flap thickness and contour to the anatomical needs of the recipient site.[17,18]

The high prevalence of diabetes mellitus (10%) and tobacco use (54%) in the study population further complicated reconstruction, as these factors impair microcirculation and wound healing, particularly in the distal lower limb where vascularity is already compromised.[19] Anatomical considerations in diabetic patients include the need for meticulous foot care to prevent recurrent ulceration, as seen in 5.6% of cases, and the use of sensate flaps to restore protective sensation in neuropathic feet.[20,21] Additionally, the study noted unique regional anatomical issues, such as tendoachilles ruptures caused by foot entrapment in Indian-style toilet pans, highlighting the need for culturally specific anatomical awareness in reconstructive planning.[22]

Anatomical considerations are paramount in guiding reconstructive options for ankle and foot defects. The choice of flap-whether local, regional, or free-must account for the region's limited soft tissue, variable vascular supply, and functional demands. Advances in perforator mapping and microsurgical techniques have improved outcomes, but challenges such as flap bulkiness and vascular complications persist, necessitating a deep understanding of ankle and foot anatomy to optimize both aesthetic and functional results.[18,23]

CONCLUSION

Soft tissue defects of the ankle and foot are commonly encountered in clinical practice, with trauma-particularly from road traffic accidents—being the leading cause, followed by falls, diabetic foot ulcers, and chronic osteomyelitis. In this study, more than half of the patients were smokers, and diabetes mellitus emerged as the most prevalent comorbidity. Preoperative evaluation included Doppler studies to assess vascular status and identify perforators for flap planning. A range of local, regional, and free flaps were utilized for reconstruction, with minimal complications and only one flap failure. Overall, patients reported high satisfaction with both functional and aesthetic outcomes, highlighting the importance of tailored anatomical considerations in reconstructive planning for the ankle and foot.

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