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Proprioception and Balance Control in Ankle Osteoarthritis and after Total Ankle Replacement: A Prospective Assessment

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Abstract: Total Ankle Replacement (TAR) could, in theory, partially restore joint sensation and motion, enhancing motor coordination, functional stability, and proprioception in a joint affected by osteoarthritis. The aim of this study is to evaluate ankle proprioception before and after a Total Ankle Replacement via an instrumental objective assessment. The evaluation of proprioceptive stability was carried out using the dedicated Delos Postural Proprioceptive System (DPPS). The clinical evaluation was performed by administering validated questionnaires, namely the American Orthopaedic Foot and Ankle Society (AOFAS) score and Short Form-36 (SF-36). Twenty patients were selected, undergoing a complete procedure with clinical and instrumental pre-operative and post-operative evaluation at the end of the follow-up. AOFAS ankle–hindfoot and SF-36 both showed a statistically significant improvement between the pre-operative and post-operative state. The postural tests performed using the DPPS showed that the affected limb showed results slightly lower than in pre-operative. In conclusion, according to the current data, the TAR does not show an improvement in proprioceptive joint stability, and although the registered mean values do not present a statistical significance, the stabilometry shows data lower than the healthy limb. In this perspective, further studies are recommended to highlight any rehabilitation scheme or protocols, using wider case series.

Keywords: total ankle replacement; osteoarthritis; proprioception; posture; delos

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1. Introduction

Proprioception is defined as the ability to sense the position of a joint in space; this skill is one of the most crucial determinants of joint stability, balance, coordination, grace of movement, and injury prevention [1]. The information from the tactile and proprioceptive receptors of the foot soles and ankle flexor muscles work together in a complementary way to maintain the standing stance [2].

Ankle proprioception is one of the most important components contributing to balance control during walking and sport activities [3]. The information from ankle receptors and the central processing are essential for postural and balance control [4]. In some sports, such as boxing, an increase in proprioceptive function and a decrease in visual dependence on postural control was evidenced [5].

Due to aging, both static position sense and the movement detection threshold appear to deteriorate. In older adults, this impaired proprioception could result in balance problems, a higher incidence of falls, and compromised quality of life [6,7].

Osteoarthritis (OA) affects around 15% of the world's adult population with joint pain and disability; approximately 1–2% is affected by ankle arthrosis [8]. Unlike other lower limb joints, ankle OA is rarely primary; the most common etiology is a previous trauma, and this implies that the patients suffering from this degenerative arthropathy are younger than the ones affected by knee or hip OA [9]. To restore pain-free ankle mobility, Total Ankle Replacement (TAR) is among the most common elective surgical procedures performed nowadays if the conservative treatment does not improve the symptoms [10,11].

End-stage osteoarthritis, on the other hand, causes a loss of cartilage and mechanoreceptors, important inflammation leading to reduced proprioception, and postural balance feedback. Abnormal proprioceptive signals not only affect sensory function but also motor control since sensory information is essential for movement programming [12]. The total replacement of the lower limb joints could, in theory, partially restore joint sensation and motion, enhancing motor coordination, functional stability, and proprioception. Knee and hip arthroplasty have been largely studied, and at 1-year follow-up after surgery, patients who have undergone these surgeries showed better unilateral balance than TAR patients [13]. These patients showed a higher dynamic postural alteration of balance, increased use of the hip strategy, and less ankle strategy to maintain their balance [14]. This finding highlights how the ankle is important for balance and how it is important to work to normalize the function of it after the surgery. Sensorimotor and neuromuscular training are programs focused on regaining proprioception and balance control [15].

The role of proprioception in Total Ankle Replacement (TAR) is a topic of growing interest in the field of orthopedic surgery. Proprioception, the sense of joint position and movement, is crucial for maintaining balance and coordinating movements. Its effects on postural stability can be quantitatively assessed under open and closed eyes conditions using a force platform, electronic mat, or accelerometers, which provide a more objective measurement than clinical scales despite an intra- and inter-subject variability of the computed posturographic parameters reported in previous studies [16,17].

In the context of TAR, understanding and optimizing proprioception could potentially enhance post-operative functional outcomes and patient satisfaction. The aim of this study is to evaluate ankle proprioception before and after a Total Ankle Replacement (TAR), implanted using an anterior approach in patients with end-stage degenerative arthropathy, via an instrumental objective assessment.

2. Materials and Methods

This is a monocentric, prospective, level II evidence study. Protocol approval was requested and granted by the Local Ethics Committee AVEC on 23 April 2020 (CE Code AVEC 139/2020/Sper/IOR); informed consent was obtained by all patients before the surgery was performed, following the principles of the Declaration of Helsinki. Recording of the study was carried out with the acronym TAR-RSA. All the data were treated with the utmost confidentiality [18].

2.1. Study Population

The criteria for inclusion included the compilation of informed consent, osteoarthritis of the ankle, primary TAR, age between 40 and 80 years, BMI < 40 kg/m^2, and the presence of patients physically and mentally inclined to perform post-operative rehabilitation plans. The final exclusion criteria for patients included articular/extra-articular malalignments > 10°, neuromuscular pathologies, end-stage knee or hip osteoarthritis (Kellgren–Lawrence > 3), talar avascular necrosis or other ankle bone loss, concurrent participation in any other experimental trial in the last 60 days prior to enrollment, documented acute or chronic disease that may affect life expectancy or make the interpretation of collected data difficult, and confirmed pregnancy or breastfeeding.

This study was performed by prospectively collecting pre- and post-operative data for all treated patients at a 10-month follow-up.

All the procedures were performed by the same orthopedic surgeon with extensive experience in foot and ankle surgery.

2.2. Surgical Procedure and Post-Operative Protocol

This study examined patients who underwent ankle TAA surgery via the implant of the Exactech Vantage® prosthetic model (Gainesville, FL, USA), with a mobile-bearing and anterior approach [11,19].

Post-operatively, a walker boot was placed for 4 weeks, and partial weight-bearing was allowed. During the stay, patients were instructed about the periodic removal of the walker boot to perform active and passive mobilization of the ankle. Three weeks after surgery, a progressive increase to a full load, protected by a walker boot for another week, was granted.

2.3. Instrumental Assessment

Proprioceptive stability was evaluated using the dedicated Delos Postural Proprioceptive System (DPPS, Delos s.r.l., Turin, Italy). This system consists of a workstation and a dedicated software (DPPS 6.0) and includes a Delos Vertical Controller (electronic postural reader, DVC), a rocking board (proprioceptive tablet unstable electronic, not used in this study), a flat electronic board, a monitor, and the Delos Assistant Desk (a horizontal bar equipped with infrared sensors, DAD) (Figures 1 and 2).

Figure 1. Dedicated workstation DELOS (DPPS, Delos s.r.l., Turin, Italy).

Figure 2. Proprioceptive control test in monopodalic support (single-stance test) evaluated via Delos Postural Proprioceptive System (DPPS, Delos s.r.l., Turin, Italy).

The DVC, applied to the sternum of the patient and fixed by elastic bands, is a two-dimensional electronic accelerometer capable of recording, after adequate calibration, the inclination of the trunk on the frontal (X) and sagittal (Y) planes. The assessment is based on the measurement of postural instability (PI), resulting, in turn, from the average instability on the frontal and sagittal planes. DAD is placed in front of the patient to allow the support of the hands in case of loss of balance. It records and measures the frequency and duration of manual patient support during testing, expressed in percentages, providing information about the so-called "precautionary strategy" through which the patient prevents the fall and restores the vertical postural [20].

The proprioceptive control tests performed consisted of static stabilometric tests in monopodalic support (single-stance test). These were characterized by four tests performed, pre- and post-operatively, on flat boards, each lasting 20 s. The first two tests were carried out with open eyes (OE), first on the healthy and affected limbs. The last two tests were carried out with closed eyes (CE) similarly. The parameters recorded and evaluated in these tests were represented by Visual Gain (the difference between OE and CE tests, indicating the visual dependence of postural stability), autonomy (the percentage of time during the test when the patient did not use the manual support on the DAD) and the so-called "Stability index" (SI, a score from 0 to 100%, automatically calculated by the software based on the autonomy and the average PI) [20]. The DPPS proprioceptive evaluation system has been previously validated in the literature [21].

2.4. Clinical Evaluation

The clinical evaluation was performed by administering, pre-operative and at the final follow-up, the validated questionnaires American Orthopaedic Foot and Ankle Society (AOFAS) score—ankle–hindfoot [22,23] and Short Form-36 (SF-36) [24,25]. The AOFAS

ankle–hindfoot score represents a clinical evaluation system frequently used to quantify the status of the hindfoot and ankle as a whole, combining subjective scores related to pain and functional limitation reported by the patient, associated with objective scores obtained via the clinical examination of the professional. It consists of three subscales for an overall score of 100 points: pain, alignment, and functionality. The SF-36 score consists of a self-administered psychometric questionnaire. It is one of the most widely used questionnaires for quantifying health-related QOL. It consists of 8 scales: mental health (MH), emotional role (RE), social function (SF), vitality (VT), physical function (PF), general health (GH), physical pain (BP), and physical role (RP). The 8 scales can be easily divided into two domains within the SF-36: a physical domain represented by the Physical Component Summary (PCS) and a mental domain represented by the Mental Component Summary (MCS) [26].

2.5. Statistical Analysis

The sample number was calculated using the software G*Power v. 3.1, considering a level of significance $\alpha = 0.05$ and a power $1 - \beta = 0.95$, with a fixed dimension of the correlation effect equal to $|\rho| > 0.50$. All variables used for the sample description were expressed in terms of mean, standard deviation (DS), and median. The normality of the distribution of variables was examined in advance by applying the Shapiro and Wilk normality test. Repeated-measures analysis of variance was used for the evaluation of clinical score trends at the end of follow-up. The non-parametric Wilcoxon signed-rank test was used to calculate the difference between paired samples. The Pearson test and the Spearman non-parametric test were used for correlation analysis of linear and monotone relationships between variables. For all tests, a p-value < 0.05 was considered significant.

Statistical analysis was performed using the IBM Statistical Package for the Social Sciences (SPSS) software version 25.0 (IBM Corp. released in 2017. IBM SPSS Statistics for Windows, Vers. 25.0, Armonk, NY, USA: IBM Corp.).

3. Results

Between December 2019 and May 2021, 34 patients with degenerative ankle arthropathy and candidates for anterior TAR surgery with mobile-bearing, 3-component prostheses Vantage Exactech® were evaluated for eligibility (Exactech, Gainesville, FL, USA). Of these, 14 were excluded (10 did not meet the pre-defined inclusion and exclusion criteria, and 4 did not consent to participation in the study). Finally, 20 patients were selected, properly informed, and enrolled. At the time of the final follow-up (10 post-operative months), 2 patients were lost (1 patient underwent a removal of the components for periprosthetic infection, and 1 patient requested to be excluded from the study already started), with a drop-out rate lower than the average described in the literature for prospective studies [18]. Therefore, patients undergoing a complete procedure with clinical and instrumental pre-operative and post-operative evaluation at the end of the follow-up were 18 (13 males and 5 females) of average age 59 ± 10.28 years (range 42–74).

The AOFAS and SF-36 (in its physical domains F and mental M) scores showed a statistically significant increase between baseline and final follow-up, with p-value < 0.005. The AOFAS ankle–hindfoot score improved from a mean pre-operative value of 33.7 (range 12–59, DS 13.65) to post-operative 85.9 (range 74–97, DS 8.26). The SF-36 score, in its two domains, F and M, showed an increase from pre-operative average values of 33.3 (range 22.8–49.5, DS 7.37) and 49.1 (range 31.9–63.1, DS 7.5), respectively, to post-operator values of 48.2 (range 43.6–56.6, DS 3.4) and 53.25 (range 40.4–60.7, DS 4.53) (Figure 3).

The results of the postural tests performed using the DELOS System (DPPS) were analyzed and processed (with an inversely proportional ratio between score to stability). The mean values of the Stability Index (SI) on the affected limb were found to be 68.58% ± 18.1 and 38.21% ± 14.5 (open-eye (OE) and closed-eye (CE), respectively). In post-operative tests, the affected limb showed results slightly lower than in pre-operative, with an SI of 61.1% ± 18.3 and 51.9% ± 13.5 (OE and CE, respectively), with a pre-post Δ not statistically

significant. No patients reported complete autonomy, both OE and CE, in single-stance support on both limbs. The recorded average pre-operative autonomy was 85.6 ± 19.6 with open eyes and 54.3 ± 21.6 with closed eyes, while the post-operative mean values were 76.8 ± 20.3 and 50 ± 18.9 (respectively, with OE and CE), with a non-statistically significant difference. The mean SI values recorded for the healthy limb were pre-operative 86.9% ± 4.5 and 52.9% ± 16.1 (OE and CE, respectively) and post-operative 85.8% ± 6.9 and 51.9% ± 13.5 (OE and CE).

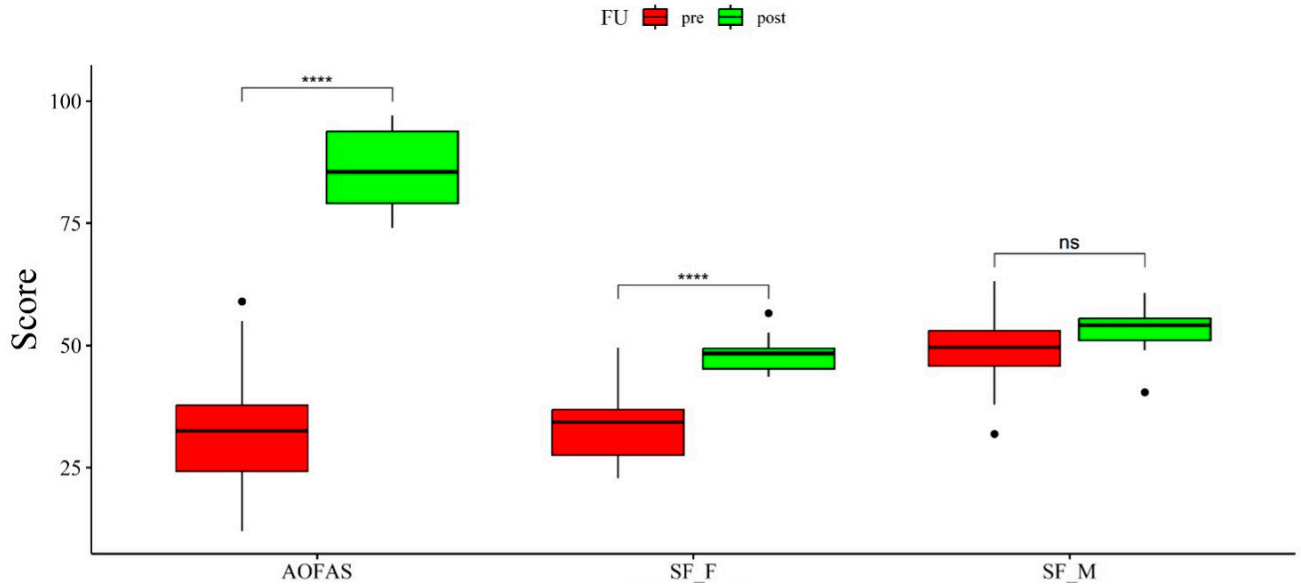

Figure 3. Boxplots representation of a pre- and post-operative comparison of American Orthopaedic Foot and Ankle Society (AOFAS) score and Short Form-36 (SF-36) scores in its physical domains F (SF_F) and mental M (SF_M). **** = $p < 0.001$; ns = non-significant.

The mean values of the autonomy on the healthy limb were 99.4 ± 1.5 and 70.1 ± 16.8 (OE and CE) in pre-operator tests, while in the final follow-up tests, were 99.1 ± 2.9 and 69 ± 17 (OE and CE). The average values were recorded, analyzed, and compared to the few related studies in the actual literature [20,21,27,28]. The SI recorded for the affected limb, both pre- and post-operative, showed modest postural and proprioceptive stability, which translated into an increased risk of falling to the ground during single-stance support (Table 1). The differences between the affected and the healthy side are statistically significant ($p < 0.005$), as opposed to the pre-post Δ.

Table 1. Mean values overview registered using Delos Postural Proprioceptive System (DPPS). Δ: Delta (difference); OE: open eyes; CE: closed eyes; T0: pre-operative; F.U.: final follow-up; TAR: Total Ankle Replacement; * statistically significant (p-value < 0.05).

	TAR Limb		Δ TAR Limb T0—F.U.	Contralateral Limb		Δ Contralateral Limb T0—F.U.	Δ TAR-Contralateral Limb at T0	Δ TAR-Contralateral Limb at F.U.
	T0	F.U.		T0	F.U.			
Stability Index OE	68.6 ± 18.1	61.2 ± 18.3	−7.4 ± 20	87 ± 4.5	85.9 ± 6.9	−1.1 ± 4.9	−18.4 ± 18.3 *	−24.7 ± 18.1 *
Stability Index CE	38.2 ± 14.5	34.8 ± 10.2	−3.3 ± 12.6	52.9 ± 16.1	52 ± 13.5	−0.9 ± 9.5	−14.7 ± 16.9 *	−17.1 ± 11.4 *
Autonomy OE	85.6 ± 19.6	76.9 ± 20.3	−8.7 ± 23.4	99.5 ± 1.5	99.1 ± 2.9	−0.3 ± 2.4	−13.8 ± 19.7 *	−22.2 ± 19.6 *
Autonomy CE	54.3 ± 21.6	50.1 ± 18.9	−4.2 ± 17.6	70.1 ± 16.8	69.1 ± 17	−1 ± 10	−15.8 ± 19.6 *	−18.9 ± 14.3 *

4. Discussion

Proprioception, the body's ability to sense its position in space, plays a critical role in maintaining balance and preventing falls. This is particularly important in the context of Total Ankle Replacement (TAR), as changes to the joint structure could potentially impact proprioceptive function.

While the specific impact of TAR on proprioception has not been extensively studied, it is reasonable to hypothesize that the procedure could have both positive and negative effects. On one hand, the correction of joint deformities and the relief of pain could potentially improve proprioceptive function by allowing for more normal movement patterns. On the other hand, the alteration of the joint structure could potentially impair proprioception.

The study by Shaffer and Harrison [29] highlights the importance of proprioception in the elderly population and the potential impact of age-related declines in somatosensory function. While this study does not specifically address TAR, it underscores the importance of considering proprioceptive function in the management of orthopedic conditions in the elderly population.

Since mechanoreceptors in musculotendinous and capsuloligamentous structures respond to the re-establishment of joint space and soft-tissue tensioning after Total Knee Arthroplasty (TKA) and Total Hip Arthroplasty (THA), a study [14] evaluated if in the ankle the damaging of the receptor were caused by the excision of the capsule, weakness of ankle plantar flexors, restricted range of motion, and altered weight bearing. No evidence was found supporting the presence of deficits in proprioception despite capsulectomy during Total Ankle Arthroplasty (TAA). In addition to that, another study [30] showed that with an anterior surgical approach, no proprioceptive deficit was caused compared to the contralateral ankle in patients evaluated using a specially constructed servo-controlled device.

The Delos Postural Proprioceptive System (DPPS) used in this study evidenced that the parameters, both pre- and post-operative in the Osteoarthritis (OA) ankle, are evidently inferior, in a statistically significant way, compared to the healthy contralateral limb, in terms of autonomy and SI. In the OA ankle, it has been evidenced that the proprioceptive stability is reduced, with increased postural waving in support and increased latency in the responses to external mechanical perturbations [30]. In addition, post-traumatic etiologies are frequent, where past acute or chronic and repeated trauma may have contributed to the damage to the mechanoreceptor structures of the joints [31].

The data recorded by DPPS, precise and already validated for the ankle [20], confirm the interesting effect that prosthetic replacement has shown on post-operative stabilometric/proprioceptive control in these patients. The reduction in post-operative mean values compared to pre-operative values (ankle affected by OA), although smaller than expected and not statistically significant, may indicate how the prosthetic replacement of joint surfaces affects the kinesthetic feedback mechanisms in some way. Moreover, in the ankle, the standard implantation of the components does not affect the ligamentous complex of the joint but "only" the resection of the osteochondral surfaces. This differs from the total replacement of the knee, which is more studied regarding proprioceptive control, although with opinions and conflicting evidence. Some authors have reported a post-operative reduction in proprioceptive control following the implantation of prosthetic models PS (posterior-stabilized), characterized by the sacrifice of the ligamentous components of the central pivot of the knee [32], while other authors found no differences in proprioceptive control between PS and CR (cruciate-retaining) [1,33]. Even though proprioception is altered in OA patients, studies have shown how with TKR, patients improved their proprioception, balance, and kinesthesia compared to AO ones treated conservatively, but they never return to normal, pre-arthritic levels [34,35]. Other studies found no difference in proprioception before and after a TKR, and one work even showed a worsening condition. There is instead some evidence that, to obtain the best results, patients should start balance and proprioception exercises immediately after TKR [1]. After a TKR, a reacquisition of

the compensatory role of the knee in balance control and the skill happens to perform an appropriate muscular activation sequence [36].

Given the statistically not significant difference in Δ pre-post, for both limbs, the obtained performance results in this study could be influenced by different factors not taken into account in this study. Therefore, further assessments to a longer follow-up are recommended to highlight any improvement or worsening trends over time.

Although the statistical correlations between the mean DPPS values and pre- and post-operative pain were not statistically significant, the role of osteoarthritic and post-surgical painful symptomatology in the proprioception of the joints and how it can affect the postural control has placed points of discussion in the scientific community. Smith et al. [37] described how patients with asymptomatic ankle OA and healthy control subjects reported similar results in balancing performance, unlike those with symptomatic OA, suggesting that from a clinical point of view, postural control deficits may be predominantly affected by pain. Similar aspects have been confirmed by other authors [38–40], placing pain at the center of postural deficits. These aspects are consistent with the work of Ashton-Miller et al., who state that rehabilitative exercise ultimately improves endurance and muscle strength but not proprioceptive balancing and coordination [41]. In this regard, the reduction in the mean values to the proprioceptive stabilometric evaluation by DPPS, taking into account vestibular, visual, and mechanoreceptor feedback (relatively little influenced by muscle strength, joint ROM, and resistance), can be considered, in a completely speculative way, confirmation of how the resections of the cartilaginous surfaces, without affecting the ligamentous apparatuses, could influence the collection of postural joint information.

This study has some limitations. The first limitation is the reduced number of patients included in the case studies who have completed all the pre- and post-operative trials and which, in some cases, has probably not allowed for an adequate statistical analysis. The second limit is represented by the short-term follow-up that does not allow for the estimation of a possible tendency of improvement or worsening in the time of the proprioceptive characteristics in the patients subjected to TAR. A third limitation can be traced back to the use of a single prosthetic model with the anterior approach.

5. Conclusions

With the current data and with the limits described above, Total Ankle Replacement (TAR) does not show an improvement in proprioceptive joint stability, and although the registered mean values do not present a statistical significance, in a way, the stabilometry shows data lower than the healthy limb. In this perspective, re-evaluation of post-operative rehabilitation trials and the pre-operative patient information should be considered.

In conclusion, while the impact of TAR on proprioception is not well understood, it is a critical area for future research. Understanding the changes in proprioception following TAR could have significant implications for post-operative rehabilitation and long-term patient outcomes.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of AVEC on 23 April 2020 (CE Code AVEC 139/2020/Sper/IOR).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

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