LEG/FOOT STIFFNESS QUANTIFICATION IN UNILATERAL TRANSFEMORAL AMPUTEE ATHLETES: IN-VIVO AND IN-VITRO APPROACHES

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Summary

Running Specific Prostheses (RSPs) provide athletes with lower limb amputation spring-like function in the affected limb. The aim of this study is to employ a multiplanar model to assess leg and foot stiffness in transfemoral (TF) amputee athletes and to identify which in-vitro stiffness parameter best represents the in-vivo behaviour. Methods include in-vivo tests on an instrumented track and in-vitro test carried out for characterising the stiffness of the running prosthetic foot (RPF). Results show that in-vivo stiffness aligns with values in literature, while in-vitro data appears to provide a comparable stiffness value to in-vivo foot stiffness.

Introduction

Human running is often modelled using a spring-mass model, where the supporting leg behaves as a massless mechanical spring loaded by the body mass [1]. The introduction of RSPs has allowed athletes with lower limb amputation running by providing spring-like leg function also for the affected limb. Previous studies have already employed simple spring-mass models to analyse differences in running mechanics between the affected (AL) and unaffected limb (UL) [2]. This study aims to evaluate leg and foot stiffness in transfemoral amputee athletes using a multiplanar model [3] specifically adapted for amputee athletes. Foot stiffness is compared to the stiffness estimate of the RPF evaluated by bench test method, in order to assess consistency and reliability across testing approaches.

Methods

Three unilateral TF athletes from the Italian national team participated in this study, each using the same model of RPF: Össur Xceed cat 2.5. In-vivo tests were carried out on the Olympia Smart Track at the Palaindoor of Padua (Italy) [4]. Tests required the athletes to run 60 m, maintaining a steady-state velocity within the acquisition volume. Kinematic and kinetic data were filtered and analysed in Matlab. Leg vector was defined from the hip joint centre to the centre of pressure (COP). Leg stiffness (K_{leg}) was computed as the ratio between the peak magnitude of the projected ground reaction force (GRF) onto the leg vector and the leg shortening [3].
In-vitro stiffness characterization of the RPF (ÖssurXceedCat2.5) was carried out through a bench test method based on midstance loading condition. The RPF was categorized by three parameters: spring-equivalent stiffness (K_{eq}), stiffening ratio and bi-axiality ratio.

In-vitro K_{eq} [5] was compared to in-vivo foot stiffness K_{foot}, computed as the ratio between the peak magnitude of the GRF onto the leg vector – defined from the centre of the clamp to the COP – and its shortening in that instant (t*). Shortening at t* was defined as the difference between the height of the centre of the clamp of the unloaded RPF when $\theta_{clamp} = 10°$ and the vertical coordinate of the centre of the clamp at t*.

Results and Discussion

Figure 1 shows stiffness values for both limbs and the prosthetic foot obtained from in-vivo data.

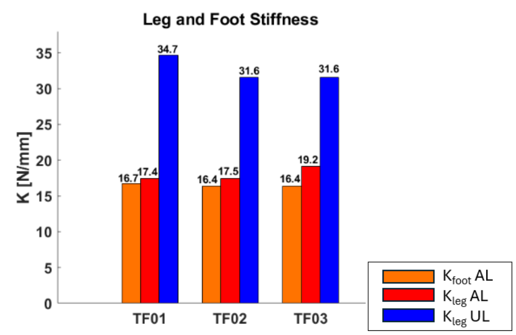

Figure 1: Leg and foot stiffness for each athlete.

Athletes reached steady-state velocities of 7.06 m/s, 6.85 m/s and 7.36 m/s for TF01, TF02 and TF03, respectively. The UL stiffness was 2.0, 1.8 and 1.6 times higher than the AL stiffness for TF01, TF02 and TF03, respectively (**Figure 1**), in accordance with previous studies [6].

Table 1: Comparison between in-vivo and in-vitro foot stiffness.

In-vivo Foot Stiffness [N/mm]			**In-vitro Stiffness** [N/mm]
TF01	**TF02**	**TF03**	K_{eq}
16.72	16.38	16.42	15.77

Results reported in Table 1 show that in-vivo foot stiffness values are very similar among athletes and that K_{eq} seems to align with in-vivo data.

Conclusions

The multiplanar model reliably captured differences between the affected and unaffected limbs. Based on the in-vitro characterization of the RPF, K_{eq} appears to accurately resemble in-vivo results. Further investigation should provide more insights into test metrics and help identify in-vitro parameters that describe in-vivo stiffness and their relation to athletes' subjective perception of stiffness.

References

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