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# Comparison of Two Methods for Ligament Prestrain in a Multibody Model of an Ankle Joint Using a Generative Approach

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**EXTENDED ABSTRACT**

## 1 Introduction

A structure is in a state of prestrain when all or some of its elements are under strain even when no external load is applied to it [1]. This phenomenon is very common in biomechanics, as experimental studies confirm that body joints exhibit prestrain, for instance in ligaments in the ankle [2].

Including prestrain in a model of the joint can be as simple as setting the slack lengths of the ligaments. Nevertheless, as prestrain is very difficult to measure in a noninvasive way, finding the correct values for the slack lengths of the prestrained ligaments is a very complex issue. In this regard, two main approaches have been employed: applying arbitrary prestrain values [3, 4] to the ligaments and choosing a strain-free location [5, 6]. In the first case, the slack lengths of the ligaments are usually obtained by shortening the lengths of the ligaments in the neutral joint configuration by 2%. In the second case, the slack lengths of the ligaments are assumed to be the same as their lengths in the strain-free configuration – effectively, prestrain is omitted. In some studies, the slack lengths of the ligaments are estimated along other parameters of the model. However, this makes it difficult to isolate the effect of prestrain and study it in detail and requires reference characteristics to optimize the model.

At this point, it is unclear, which approach to prestrain offers results closer to that of the actual joint. Furthermore, comparing the methods for prestrain would require a large database of joint models with corresponding reference characteristics. Therefore, the aim of this study was to address this issue with a generative approach. The main idea of the method was to use an existing model of the ankle joint and generate varied, prestrained variants based on it. Then compare the prestraining approaches using the generated models, for which all of the important characteristics can be obtained numerically. A method for generating varied, prestrained ankle models based on a single multibody ankle joint model was proposed. The method was used to generate 30 prestrained ankle models, which were then solved in statics under the two approaches to ligament prestrain. The obtained results were then compared to the reference characteristics of the prestrained models.

## 2 Method

As mentioned before, the main aim of the study was to compare the methods for ligaments prestrain in a multibody ankle joint model. The prestrain approaches were tested on a varied set of generated multibody ankle models. The process of model generation used the model in [5] as a baseline. The base model parameters, both geometrical and material, were perturbed by up to ±0.5 mm and 3% respectively. Then, the lengths of the ligaments in the model were computed in its neutral location and randomly modified - shortened or elongated. These modified lengths were assumed to be the slack lengths of the ligaments. The slack lengths obtained in this way ensured that the generated model was under prestrain. This meant that the initial neutral location could no longer be the rest location of the model. Therefore, the new rest location was obtained numerically. The process of model generation was repeated multiple times to obtain 30 models, which did not exhibit numerical problems in statics.

The prestrain approaches were then tested on each generated model. This was done by recomputing the slack lengths in the new rest location and shortening them according to the selected prestrain approach. The generated models along with their prestrained variants were then solved in statics for moment loads from -5.0 Nm to 5.0 Nm. The obtained characteristics of angular displacement with regard to the moment load were then numerically compared between the studied variants and the reference from the original, generated model. The prestrain variants tested in this study included: a strain-free configuration, 2% shortening of the ligaments.

## 3 Results and discussion

The generated models used in this study can be seen in Fig. 1a. The models had a geometry and material parameters similar to that of an ankle joint. The slack lengths of their ligaments as well as their reference characteristics (see Fig. 1b) were known. Furthermore, the angular displacements of the models were similar to that of the ankle joint. This meant that, when these models were subjected to different prestrain approaches, actual numerical comparison between them and the ground truth could be obtained.

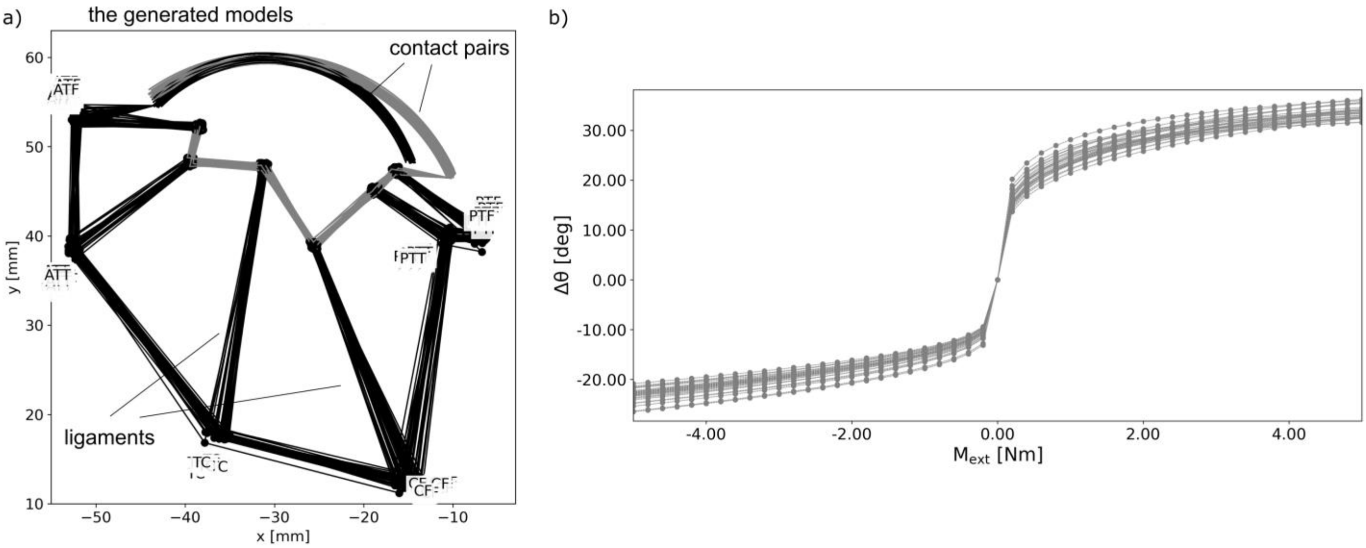


Figure 1: a) The generated models of the ankle used in this study; all (30) generated models were drawn one on top of another, in one figure, to show how much the models varied in terms of geometry (where: ATF, ATT, TC, CF, PTT and PTF were the ligaments of the ankle joint), b) the angular displacements of all the models with regard to the external moment load superimposed in one figure

The generated models had an average prestrain of 1.68% on all of the ligaments. Due to numerical problems with solution after parameter perturbation, to generate 30 viable models 70 iterations were necessary. This meant that the success rate of the generation was at 43%.In terms of the comparison between the prestrain approaches, in 63% (19 out 30) models the approach using the strain-free configuration offered results closer to that of the reference from the generated model. To further analyze the results, relative differences between the angular displacements of the reference and the prestrained variants were obtained. In this case, the variants with strain-free configuration had an average of 13.2% in terms of the relative difference, while the 2% shortening averaged at 25.7%. This meant that the angular displacements of the variants with 2% shortening significantly more different from the reference than in the case of strain-free approach. The results, along with some other practical implications [5], make the strain-free configuration an interesting choice, when modeling the ankle joint. Nevertheless, due to the assumptions undertaken in this study, the findings should be interpreted with caution. The generative process was setup to search for models in the vicinity of the baseline model from [5]. While the generated models had visibly different parameters, it is unlikely that the variants represent all the aspects of the ankle in the general population. This could be at least partially alleviated in the future, by carrying out the experiment on a larger database of models with more extensive parameter modification.

## 4 Conclusion

In this study, an approach for generating prestrained ankle models based on a reference model was presented. The method had a relatively high success rate of 43%. The obtained models featured ankle-like geometry and responses to load in a functioned, while their ligaments had an average prestrain of 1.68%.

The generated models were then employed to test two common approaches to prestraining ligaments in biomechanical models: strain-free approach and 2% shortening of the ligaments. The strain-free approach was found to offer results closer to that of the reference in 19 out of 30 cases. Nevertheless, this finding should be interpreted with caution, as the generated models might not represent all of the aspects of the ankle joints found in general population.

## References

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