Institute of Medical & Biological Engineering

# Lack of Standardisation in Mechanical Testing of the Patella Tendon: A Review and Guide

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## Background

The patella tendon (PT) is commonly used as a graft material for anterior cruciate ligament (ACL) reconstruction following injury [1]. Since the purpose of the graft is to replace the mechanical function of the damaged ACL, an understanding of the mechanical properties of the PT is required. Various PT mechanical properties have been investigated [2]:

- Load at failure and strength (ramp testing)
- Equilibrium stress and modulus (stress relaxation testing)
- Dynamic modulus (cyclic testing)

These reported mechanical properties may be affected by variations in key parameters of the testing protocol [3], including:

- Pre-conditioning regime (Fig1A)
- Strain rate (Fig. 1B)
- Maximum strain (Fig. 1C)
- Number and frequency of cycles (Fig. 1D)

To compare data obtained by different investigators, a consensus methodology for the mechanical testing of the PT must be identified.

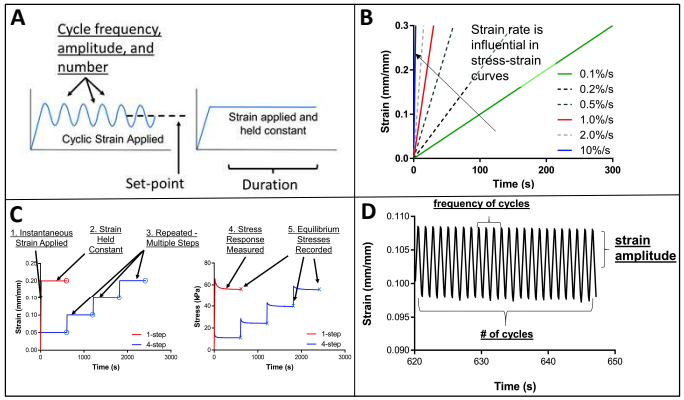


***Figure 1**: Parameters that may be varied during preconditioning (**A**), ramp testing (**B**), stress relaxation (**C**), and cyclic testing (**D**). Adapted from [4].*

## Methods

1. Systematic literature search

A PubMed search was performed using the search term [("patella tendon") AND ("*mechanical testing" OR "*mechanical properties" OR "tensile testing" OR "strength testing")] and limited to records published in the past ten years (2010-2020). This returned a total of 143 publications for handsearching, of which 50 were included for further evaluation (Table 1).

| Source | Human | Mouse | Rat | Ox | Pig | Rabbit | Sheep |
|---|---|---|---|---|---|---|---|
| # of studies | 16 | 15 | 10 | 3 | 3 | 2 | 1 |

***Table 1**: Source of tissue used in tensile testing of patella tendon 2010-2020.*

Since twenty-two studies involved more than one type of tensile test (e.g., cyclic testing followed by ramp to failure), a total of 81 mechanical tests were evaluated.

2. Methodological review

For each type of test, a record was made of the key parameters employed during pre-conditioning and the main test. This allowed quantification of the range and modal values for each test parameter.

## Results

- In those tests that employed cyclic preconditioning, the number of cycles varied across a range of 10-250 cycles (Fig.2A). The modal value for cycle number was 10 cycles, and the second most common number was 25 cycles. The upper and lower limits of each cycle were determined variously by force or strain.
- In most reports of ramp-to-failure testing, the strain rate was not given. The reports from only 16 tests included strain rates (Fig.2B). The modal strain rate was 0.1 $\%s^{-1}$ followed by the second most common rate of 10 $\%s^{-1}$.
- In the 12 stress relaxation tests included in this review, the final/maximum strain, number of relaxation steps, and time at each step were parameters that varied. The most common final/maximum strain was 8 % (Fig.2C), and the maximum strain was typically reached in 3 steps.
- A total of 20 cyclic tests were described in the reports. The number of cycles performed at each testing frequency/set-point varied between 10-1000, and the most common number used was 20 cycles (Fig.2D).

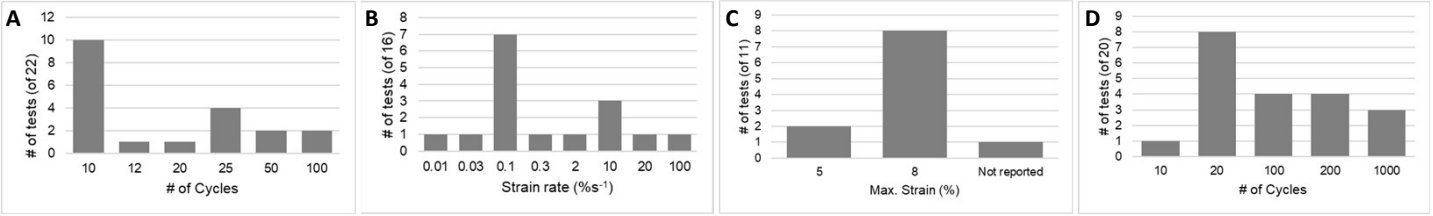


***Figure 2**: The frequency of tensile tests employing different values for number of cycles during pre-conditioning (**A**), strain rate during ramp testing (**B**), maximum/final strain during stress relaxation testing (**C**), and number of cycles during cyclic testing (**D**).*

## Conclusion & Future Work

- There is a lack of standardisation in protocols used in the mechanical testing of the PT. This has implications for the comparison of studies conducted using different protocols, and has led to potential for misinterpretation of mechanical data.
- A series of validation studies is proposed to systematically compare the mechanical measurements obtained from PT using different methodological approaches.

## Impacts

- Academic: Determining the effect of varying key parameters during mechanical testing will ensure that rigorous conclusions can be made about PT mechanical properties, and that research from different laboratories can be confidently compared.
- R&D: A standardised methodology for PT testing will provide a rational basis on which to conduct pre-clinical evaluation of native and tissue engineered PT grafts for ACL reconstruction.
- Clinical: An understanding of the true variation in PT graft mechanical properties will better enable surgeons to select the most appropriate graft for ACL reconstruction and may reveal the potential for graft stratification in different patient groups.

**References**

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[2] Johnson, GA et al. (1994). J Orthop Res. 12(6):796-803
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[4] Patel, JM et al. (2019). Tissue Eng Part C Methods. 25(10):593-608

**Acknowledgements**

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