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**Title**
Mechanical testing of polyurethane foams to cover lower limb prostheses

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**Summary**
Despite the aesthetic and functional importance of foam cosmeses, the foam mechanical behaviour has not been quantified in the literature. This paper reports the results of testing two commonly used foams to determine their material properties. The works aims to enable the FEA modelling of cosmeses.

**Introduction**
In contrast to the improvements made in lower limb prosthetic components over the last thirty years1, the design of Polyurethane (PU) cosmeses (which protect the components and provide an aesthetic finish) has not changed. This is surprising because there are obvious problems with current cosmeses; they are known to influence the function of knee and ankle components and often rupture. Furthermore a sample population of U.K. amputees reported poor satisfaction for all cosmesis features listed in the study questionnaire2. Despite these limitations, there are no studies of cosmesis PU foams reported in the scientific literature. Consequently the mechanical performance of current cosmeses is unknown. This basic information is required for the development of Finite Element (FE) models aiming to improve cosmesis design. The objective of this study was to determine mechanical properties of two PU foams used to manufacture cosmeses (for use in FE models) and compare their performance.

**Methods**
International Organization for Standardization (ISO) testing protocols for flexible cellular polymeric materials were used. Five protocols were identified which were considered to provide mechanical properties relevant to the particular application of the foam; tensile3 and tear4 strength, compressive stress5and compression creep6. As no ISO standard exists for testing this material in tensile creep, the compressive creep protocol6 was modified: identical number

of samples, test duration and measurement points were used however the specimen was loaded to a constant load which corresponded to 70% strain in the tensile strength test.
Blocks (0.5m3) of PU foam used by two cosmesis manufacturers were procured. Test samples were cut from the blocks to the specification in the relevant ISO standards. The sample shape specified in 3 was used in the tensile creep test. All samples were cut using a band saw and the tensile samples required additional fine cutting using a scalpel blade.

**Results**

The mechanical properties determined are summarised in Table 1. Values reported are the mean or median value of each test series (specified in each ISO standard) calculated from 2-5 samples. This accounts for repeatability and sample variation.
By law the cosmesis foam needs to be flame retardant and comply with EN 22523 flame retardancy test prior to CE marking. Adding flame retardancy material may affect the mechanical properties of PU foam. However the clinical benefit of reducing risk to amputees is deemed more important than any negative effect on foam properties.

**Conclusion**

Foam 1 was found to have greater ultimate tensile strength, tensile modulus and tear strength but lower compressive modulus compared with Foam 2. Foam 2 has marginally superior creep properties compared with Foam 1 (zero percentage creep strain and recovery would mean that after the load has been applied the foam does not further deform over a period of constant load and returns to its original shape once the load has been removed). However the comparative performance of the two foams needs to be evaluated in terms of the properties that are desirable or required in cosmesis foam. For example is a high tensile or compressive modulus appropriate when the foam is known to negatively influence joint function? Appropriate foam properties have not been quantified to date and are likely to vary with each prosthetic prescription. The properties presented here will be used to develop FE models which aim to evaluate appropriate foam properties for cosmesis function and optimise them.

**References**

1 Laferrier JZ, Gailey R. Advances in lower-limb prosthetics technology. Physical Medicine and Rehabilitation Clinics of North America 2010;21:87-110.

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3 Institution, B.S., Flexible cellular polymeric materials- Determination of tensile strength and elongation at break, in BS EN ISO 1798:2008.

4 Institution, B.S., Flexible cellular polymeric materials- Determination of tear strength, in BS EN ISO 8067:2008.

5 Institution, B.S., Flexible cellular polymeric materials- Determination of stress-strain characteristics in compression- Part 1: Low-density materials, in BS EN ISO 3386-1:1997.

6 Institution, B.S., Flexible cellular polymeric materials- Determination of creep in compression, in BS EN ISO 10066:1998.

**Image:** Table1_1148.png

Table 1. Summary of Mechanical Properties.

| | Number of samples | Foam 1 | Foam 2 |
|---|---|---|---|
| Ultimate Tensile strength | 5 | 216 kPa | 183 kPa |
| Tensile modulus (calculated over strain range 10-100%) | 5 | 51 kPa | 42 kPa |
| Compressive modulus (calculated at 30% strain) | 3 | 19 kPa | 22 kPa |
| Compressive modulus (calculated at 70% strain) | 3 | 12 kPa | 17 kPa |
| Tear strength | 3 | 7 N/cm | 6 N/cm |
| Compressive creep strain | 2 | 16% | 7% |
| Recovery after compressive creep test | 2 | 3% | 2% |
| Tensile creep strain | 2 | -28% | -27% |
| Recovery after tensile creep test | 2 | -16% | -10% |