Biomechanical evaluation comparing Pulvertaft weave and side-to-side tenorraphy using porcine tendons

Sajid S, Day E, Kuiper J H, Singh R, Pickard S

Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry, SY10 7AG

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Abstract

Background

Tendon transfers are used to restore function to limbs. Allowing immediate movement after surgery has several advantages including preventing adhesions, improving vascularity and allowing earlier restoration of function. Pulvertaft Weave (PTW) and Side-to-Side (STS) are accepted methods of tenrrhaphy. This study aims to compare these methods in terms of creep after cyclic loading.

Methods

Fresh porcine flexor digitorum tendons were used. Ten tendon PTW and ten STS repairs were performed. Cross sectional diameter was measured. The tendon repairs were tested by applying tension up to 25N for 100 cycles, followed by tension up to 75N for 100 cycles, followed by loading to failure. Force-displacement data was used to determine the creep of the repaired tendon.

Results

All tendons survived 100 cycles of loading at 25N. After 1 cycle of loading, the mean cyclic creep in the PTW group was almost 3 mm larger than in the STS group (p=0.046). After 100 cycles, the mean cyclic creep in the PTW group was 4.4 mm larger (p=0.008). The cyclic creep rate was significantly larger in the PTW group (p<0.001).

All STS but only four PTW repairs survived after cyclic loading at 75N (p=0.01). After 1 cycle and 100 cycles, mean creep of the surviving PTW samples was almost 7mm (p=0.006) and almost 9mm (p=0.004) larger than the STS group.

The mean load to failure was four times larger in the STS group than the PTW group (p=0.004).

Conclusions

STS repairs have a significantly smaller permanent elongation after cyclic loading at 25N and 75N, a significantly smaller cyclic creep rate, require a significantly larger load to fail.

This implies that STS repairs are less likely to elongate after cyclic loading and can withstand greater loads. These properties can be valuable in allowing patients to commence mobilisation immediately after surgery.

Introduction

Tendon transfer surgery is a commonly performed procedure to restore function to limbs [1]. Allowing immediate movement is advantageous for patients as it allows them to adapt to the transfer, commence rehab and ultimately gives earlier restoration of function [2,3]. There is also evidence that early mobilisation prevents adhesions, allows for increased tensile strength of the anastomosis and improved vascularity [2,4-6].

Early mobilisation is essential for rehabilitation and this is particularly so when transfers are being done for reconstructive hand surgery in tetraplegia [7,8,]. It has been documented that early passive mobilisation is beneficial for rehabilitation in terms of vascularity and cellularity of tissues, prevention of adhesions, reduction of joint stiffness and facilitation of healing [5,6]. Active mobilisation has also been shown to be of advantage, allowing earlier return to function, preventing disuse atrophy and encouraging motor recruitment activity [3, 7-9]. The concerns that early activity can lead to failure of tendon transfer is unfounded and it has been shown that return to function can be achieved more quickly with immediate mobilisation [9,10].

To allow immediate mobilisation the repair needs to be strong enough to withstand physiological loads. Several studies have directly compared PTW and STS tenorrhaphy in terms of biomechanical properties [4,11-13]. These studies provide evidence that STS repair has more favourable biomechanical properties in terms of load to failure, ultimate load and stiffness [4,7,12]. These preferable properties can help to achieve early mobilisation with the associated benefits [4,11,12]. However, the detail of how these repairs behave during cyclic loading at the low load levels expected during rehabilitation exercises has not been shown. This is an important aspect to consider as tendon repairs are unlikely to be loaded to their ultimate strength during the early post operative phase [14].

How the repairs behave with cyclic loading will have an impact on the longer-term outcome for patients. This article therefore aims to compare the differences in cyclic elongation (cyclic creep) between PTW and STS repair methods during cyclic loading. It also aims to compare if there is a difference in the load to failure between the repair techniques after cyclic loading.

Method

Porcine tendons were used in the study. Fresh flexor digitorum tendons were harvested from the forefoot of the animals. All repairs were performed by one of the authors (ED) who was specifically trained in the technique by the senior author (SP). A total of 20 tendon repairs were made, 10 of each type. The amount of overlap between the two tendon ends for all repairs was 50mm (Fig 1). For the PTW repair the distal tendon was woven through 3 horizontal incisions in the proximal tendon. The repair was held using 3 evenly placed 3-0 polyester sutures (Ethibond Excel, J&J Ltd, Maidenhead, UK). For the STS repair, 4 evenly placed polyester (Ethibond) 3-0 cross sutures were used. The specimens were stored in saline solution in a refrigerator prior to testing to prevent them drying out.

The cross-sectional dimension in the direction of the largest and smallest dimension was measured for each tendon using digital callipers before commencing mechanical testing. A characteristic diameter was then calculated assuming the tendons had an elliptic cross section, in other words the geometric mean of the two dimensions.

The mechanical testing was performed using a servo-mechanical materials testing machine (100-Q-225-6, TestResources Inc, Shakopee, MN, USA). The tendons were mounted vertically between two clamps placed 70mm apart, ensuring the repair was positioned centrally. The tendon repairs were then tested by applying 100 cycles of tensile forces between 5 and 25N, followed by 100 cycles between 5 and 75N, both at 0.5 Hz. The two cyclic load magnitudes were based on *in vivo* measurements of forces in the flexor digitorum profundus tendons of 12 patients during rehabilitation exercises, which found a mean peak force of 24N and a maximum peak force of 75N [15]. After the cyclic loads, the tendons were loaded until failure of the repair at a rate of 10mm/min. Force-displacement data was collected at a rate of 10Hz using the machine's inbuilt sensors.

The force-displacement data was used to determine the elongation of the repaired tendon after each cycle of loading. The amount of elongation after each load cycle was regarded as the "cyclic creep". For the 25N cyclic load, the cyclic creep rate of each specimen was determined as the slope of the least-square fit between the log of the cycle number and the cyclic creep. A deformation equal to half the overlap (25mm) was assumed to denote failure, and for each repair the force needed to achieve this deformation was determined. The mean cyclic creep after 1 cycle and 100 cycles of load at 25N and 75N, the cyclic creep rate at 25N and the force to achieve 25mm of elongation was compared between the two groups using ANCOVA, with the characteristic diameter as a covariate. The number of repairs in each group surviving each cyclic loading phase was compared using a Fisher’s exact test. All statistical analyses were performed using R vs 3.6.0 (R Foundation for Statistical Computing, Vienna, Austria). A two-sided p-value below 0.05 was assumed to denote significance.

Results

Characteristic diameter

The mean characteristic diameter of the 10 PTW tendons was 4.4mm and that of the 10 STS tendons was 5.3mm, with no significant difference between the two groups p=0.12, Table 1). This indicates that the two groups in terms of diameter are comparable.

Cyclic loading at 25N

All tendon repairs in both groups remained intact after cyclic loading at 25N. The mean cyclic creep versus load cycle for both repairs is shown in Fig. 2, suggesting that cyclic loading generated a larger amount of creep in the PTW group.

After 1 cycle of loading, the mean cyclic creep in the PTW group was almost 3 mm larger than in the STS group, a significant difference (p=0.046, Table 1 and Fig. 3).

After 100 cycles, the mean cyclic creep in the PTW group was 4.4 mm larger (p=0.008, Table 1 and Fig. 4). The cyclic creep rate was also significantly larger in the PTW group (p<0.001, Table 1).

Cyclic loading at 75N

All tendon repairs in the STS survived but only four out of the 10 tendon repairs in the PTW group remained intact after cyclic loading at 75N, a significant difference (p=0.01, Fisher's exact test). Five samples in the PTW group failed during the first cycle and never achieved a load of 75N, and 1 sample failed after 30 cycles. After 1 cycle and 100 cycles, mean creep of the surviving PTW samples was almost 7mm (p=0.006) and almost 9mm (p=0.004) larger than that in the STS group (Table 1, and Fig. 5 and Fig. 6)

Load to failure

The mean load to achieve 25mm displacement, which we regarded as failure, was almost four times larger in the STS group than in the PTW group (336 vs 86 N, Table 1 and Fig. 7), a significant difference (p=0.004, Table 1).

Discussion

This study shows that STS repairs have a significantly smaller permanent elongation upon mean levels of cyclic loading measured during rehabilitation exercises, a significantly smaller cyclic creep rate, require a significantly larger load to achieve 25 mm of elongation and are significantly more likely to survive the maximum level of cyclic loading measured during rehabilitation exercises. The difference in elongation is already apparent after 1 cycle of loading at a rehab load and increases with cyclic loading and greater loading force.

Our work has shown that STS has a better biomechanical profile in terms of elongation after cyclic loading and creep compared to PTW. These repairs are less likely to elongate after cyclic loading and can withstand greater loads. These properties can be valuable in allowing patients to commence mobilisation and rehab immediately after surgery; with all the advantages that this confers in terms of preventing adhesions, improving vascularity and cellularity of tissue, reducing stiffness and aiding healing [2-10].

We accept that there is a difference in the amount of sutures placed in the two repairs. Only three weaves were possible for PTW for the given overlap distance. Therefore only three sutures were placed. However, multiple cross sutures were placed for the STS repair. The difference in the amount of suture material may influence the results. The placement of sutures is part of the technique of the two repairs and reflects clinical practice. Standardising the amount of suture material will result in altering the repair technique itself and the addition of further sutures to the Pulvertaft Weave may risk cutting through the weave.

We acknowledge that this study along with the previous ones comparing PTW and STS [4,11-13] only compare the repairs in vitro. The effect in clinical practice needs to be reviewed to compare the outcome of these repairs in patients. However, clear definition points would need to be agreed on to achieve this.

Our study has shown that PTW repairs had significantly greater elongation after cyclic loading and generated significantly more creep than STS repairs, which implies that PTW repairs are more likely to stretch out further with use.

In our unit, the transition from using PTW to STS tenorrhaphy resulted in three patients undergoing Alphabet procedures required revision surgery of the brachioradialis to FPL transfer to correct the tension, as the repairs did not stretch out as expected. However greater confidence in our tenorraphy has enabled us to abandon daytime splintage in selected patients.

Surgeons need to be aware of the difference in the characteristics of biomechanical properties when performing these repairs and set the tension in of the repair appropriately.

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Figure 1

Sample tendon repairs showing overlap of 50mm

A: Pulvertaft weave

B: Side-to-side repair

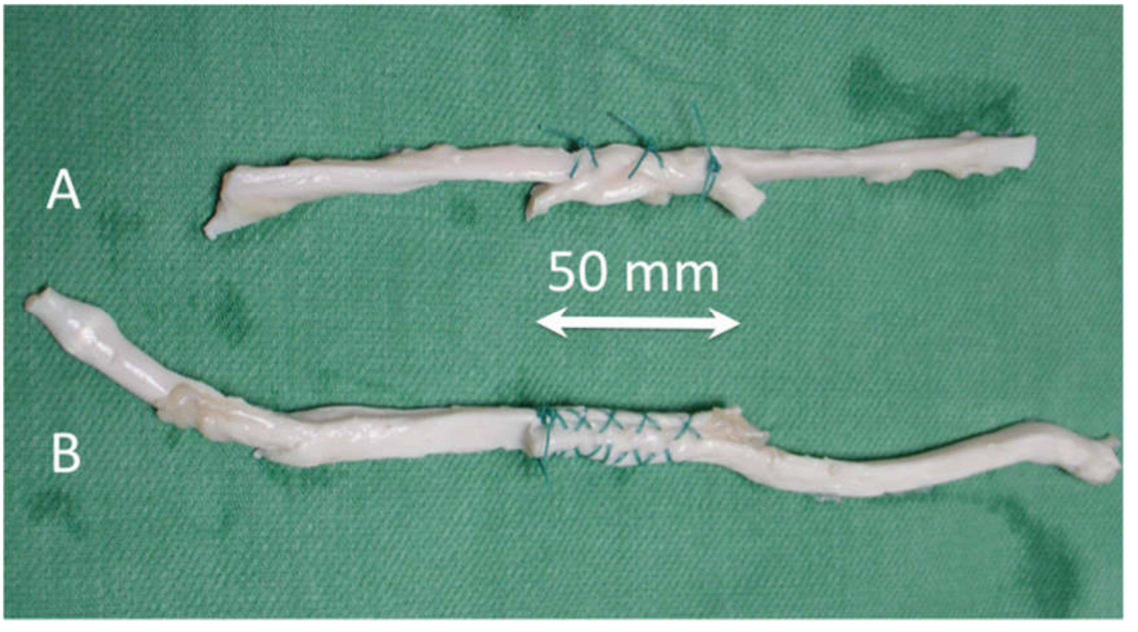

Table 1

Characteristic diameter and cyclic creep for the two tendon groups at the two load levels

	PTW mean (SD)	STS mean (SD)	Difference (95% CI)	p-value
Characteristic diameter	4.4 (1.3)	5.3 (1.2)	0.9 (-0.3-2.1)	0.12
Creep at 25 N				
After cycle 1	7.8 (2.9)	5.2 (2.5)	2.8 (0.1-5.6)	0.046
After cycle 100	10.7 (3.3)	6.5 (2.6)	4.4 (1.3-7.4)	0.008
Creep at 75 N				
After cycle 1	14.1 (5.2)	7.1 (2.6)	6.9 (2.4-11)	0.006
After cycle 100	17.5 (5.7)	8.6 (2.7)	8.9 (3.8-14)	0.003
Load to failure (N)	86 (57)	336 (194)	186 (67-304)	0.004

Notes: All values in mm, except Force. Confidence intervals and p-values based on an independent t-test (diameter) or ANCOVA (creep). Differences in mean creep and load to failure adjusted for characteristic diameter. Creep from cycle 1 to cycle 100 at 25N differed significantly between the two groups (p=0.005 for interaction term repair*cycle in repeated measures ANOVA). Mean creep at

75N for the PTW group, and comparison with the STS group, was based on the surviving PTW samples: n=5 after 1 cycle and n=4 after 100 cycles.

Figure 2.

Mean cyclic creep versus load cycle for PTW and STS repairs.

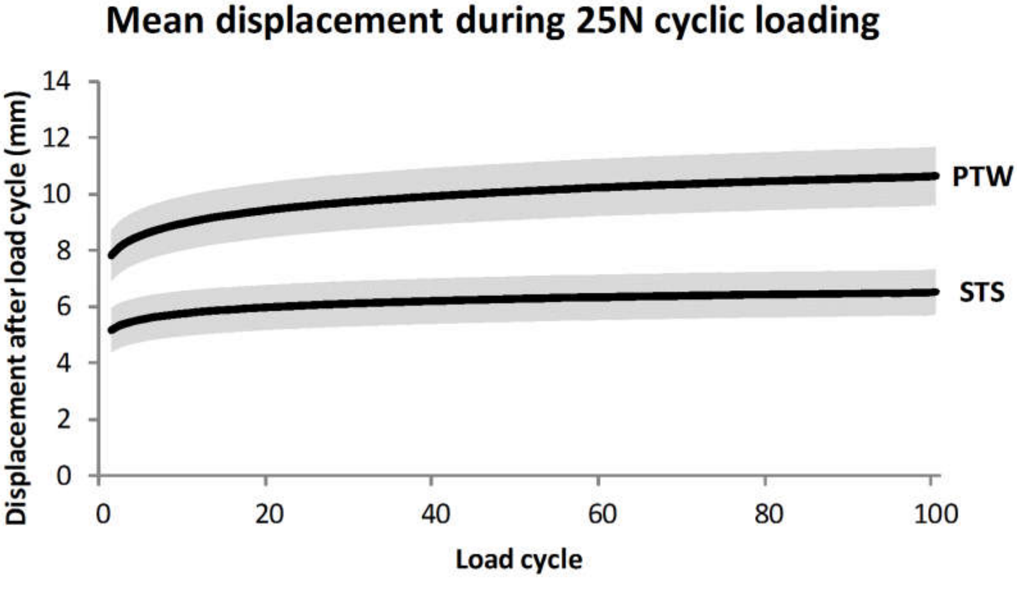

Figure 3:

Difference in displacement after 1 cycle of loading at 25N

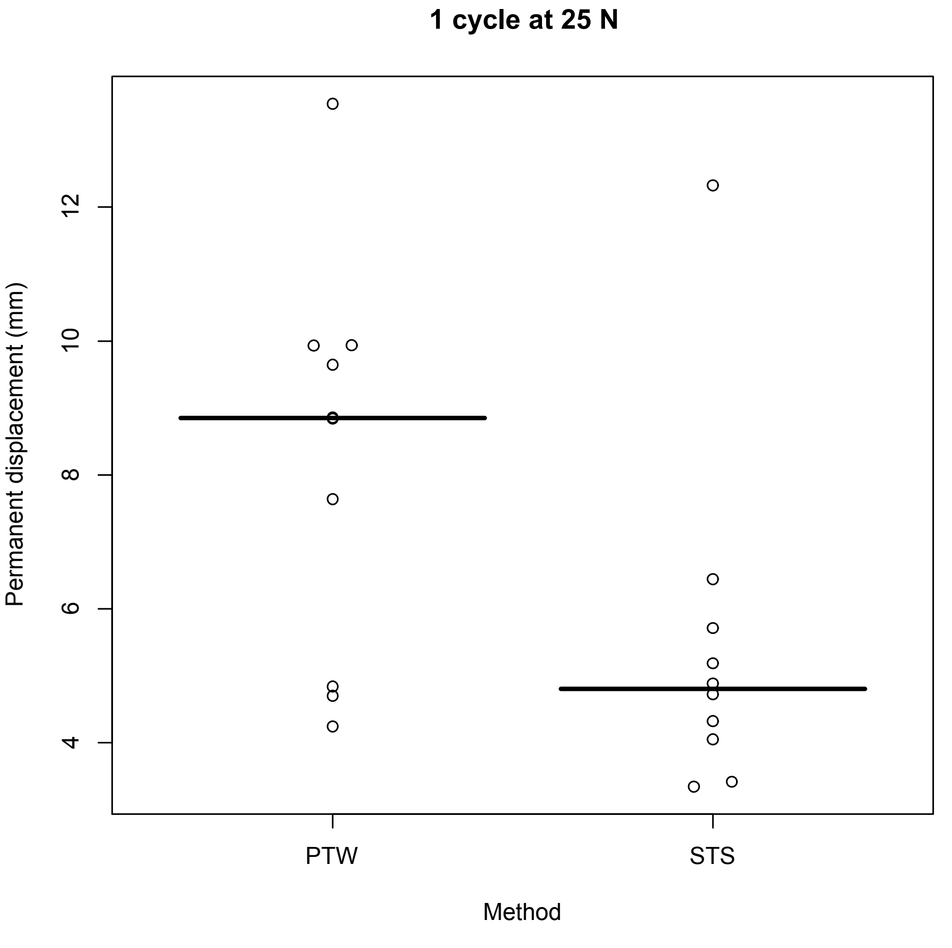

Figure 4

Difference in displacement after 100 cycles of loading at 25N

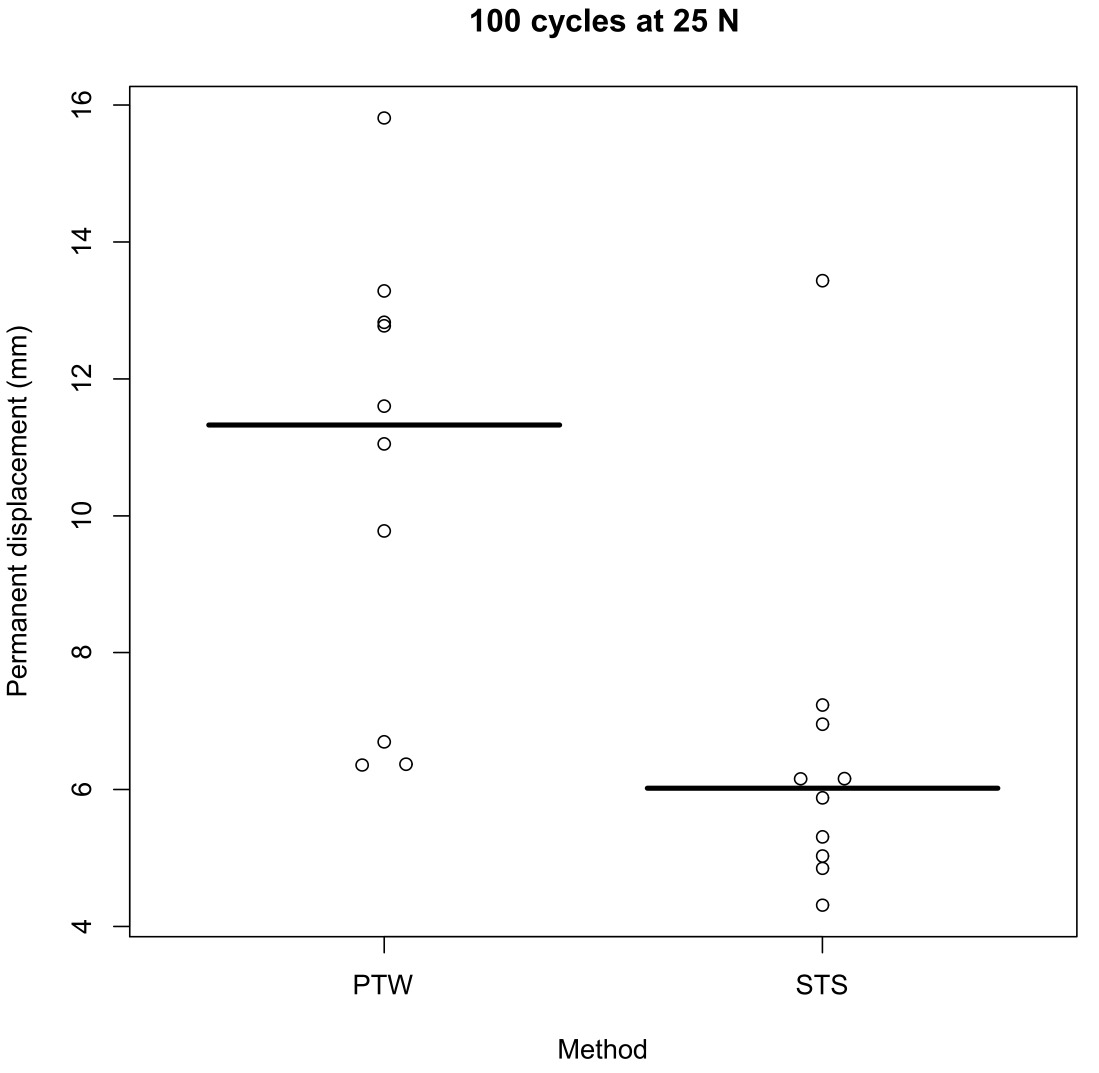

Figure 5.

Difference in displacement after 1 cycle of loading at 75N

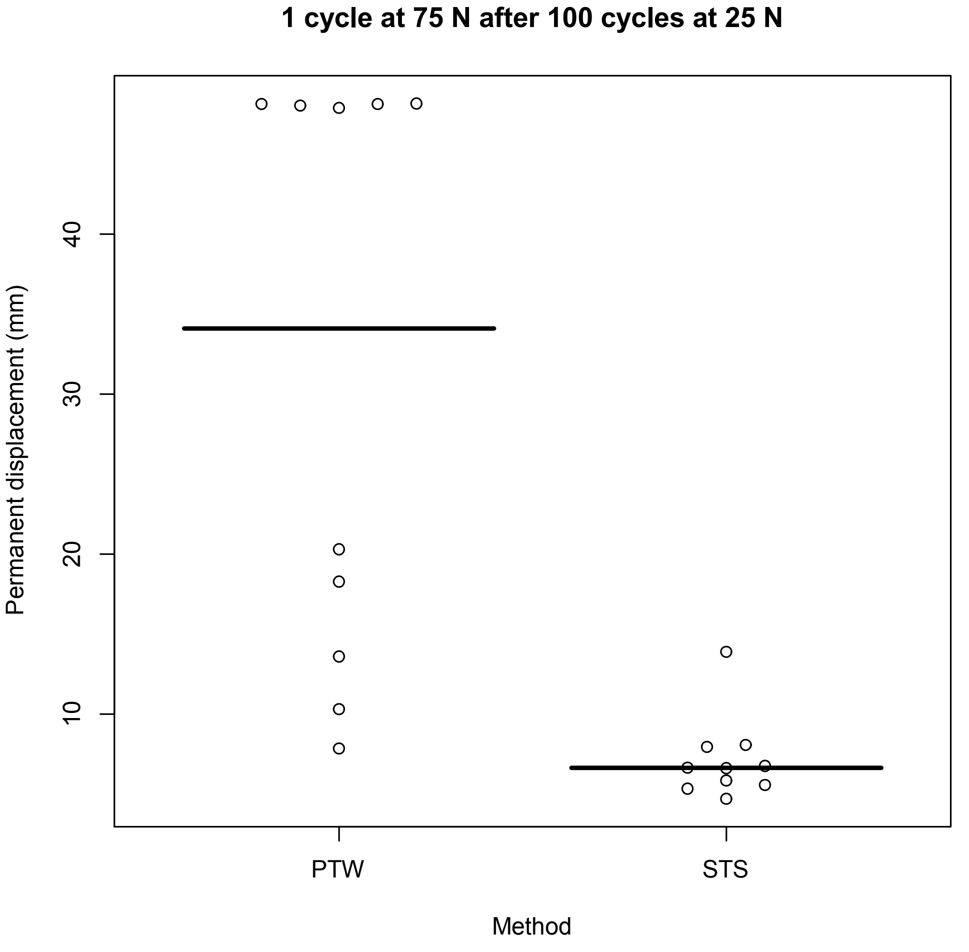

Figure 6.

Difference in displacement after 100 cycles of loading at 75N following 100 cycles of loading at 25N

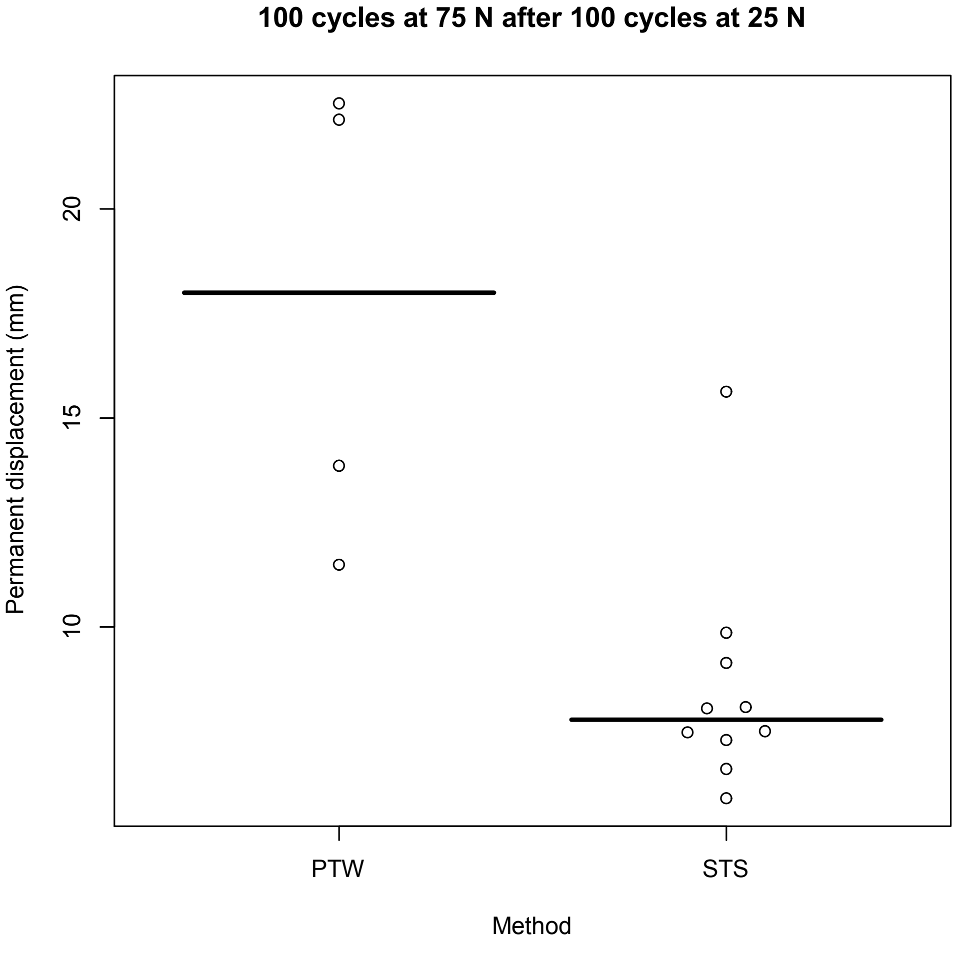

Figure 7

Mean load to failure (regarded as 25mm displacement)