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1. Introduction

Arthrodesis of the shoulder joint consists in immobilizing both scapula and humerus in a physiologic position with a plate and screws construct in order to achieve solid bone fusion. This palliative surgical procedure is commonly used to manage severe degenerative, traumatic and congenital shoulder pathology (Fitzpatrick *et al.*, 2012).

Its results are good to excellent in 87.5 % of cases and limb function is often considered acceptable (Pucheu & Duhautois, 2008). However, construct failure is a frequent complication of canine shoulder arthrodesis and is often related to an insufficient bone anchorage of screws in the scapula (Fitzpatrick *et al.,* 2012).

The scapular plate location is along the basis of the scapular spine, craniolaterally where the bone is significatively thicker according to a morphometric study (Ocal & Toros, 2007). Given the plate contouring and screw angulation needed, the most commonly used plates are Dynamic Compression Plate (DCP) and Low Compression DCP (LC-DCP).

While some authors advocate the use of a second plate located caudolaterally in order to strengthen the construct (Fitzpatrick *et al.,* 2012; Kalff & Gemmill, 2012; Oxley, 2017), we wondered if we could improve its strength with a recently introduced model of Polyaxial Locking System (PLS) allowing free orientation and locking of the screws up to 15° angulation.

The aim of this study was to compare the scapular stability of DCP and PLS constructs. We hypothesized that the PLS with a 15° sagittal divergence of implantation of the locking screws would yield a higher linear stiffness and pullout strength than the DCP construct under wire traction tests inspired by Acquaviva *et al*. (2012).

2. Methods

2.1 Sample preparation

Nine pairs of scapulae were harvested from adult dogs between 25 and 35 kg. Dogs were of similar size and died from reasons unrelated to this study. After careful removal of the soft tissues, macroscopic examination was performed to rule out any abnormality. An osteotomy of the scapular neck allowed us to remove irregular periarticular bone processes.

2.2 Implant design

We implanted all scapulae with 3 self-taping screws per plate which is the minimum number in the scapula according to the standard surgical technique. We used 3D printed drilling guides to ensure a predetermined angulation of the screw and a 45° angulation of the plate with the scapular spine & supraspinous fossa.

We made two groups of scapulae, in both groups we had scapulae of the 9 dogs. In the first group, we used DCP 3.5 mm and positioned the screws perpendicularly to the plate. The second group was implanted with PLS 3.5 mm (PLS®, Aesculap B. Braun Vet Care; Tuttlingen, Germany). The middle screw was perpendicular to the plate while the two other screws were angulated 15 degrees away from the middle screw.

Then, the implanted samples were included in polyurethane resin.

2.3 Biomechanical testing

Traction was exerted through a wire rope on the first free distal hole in the plate. The eighteen tests were performed using a traction system (AGS-X Shimadzu, Japan) with a pretest of 20 mm/s traction until the strength reached 10 N, straightening the system. The test consisted then in a 1 mm/min traction to failure. Failure was considered when the strength decrease was more than 10 % of maximum measured.

2.4 Data acquisition and processing

During tests, acquisition of data was carried out using TrapeziumX software (Shimadzu, Japan).

Linear stiffness was assessed by calculating the slope of the low displacement curve in its linear interval for each pullout test. Failure mode, load of failure and linear stiffness were compared. Results were statistically analyzed using R software (R.app 3.6.2, GUI1.70; R Foundation for Statistical Computing). Significative difference was set at $p < 0.05$.

3. Results and discussion

We observed three different mode of failure (Figure 1): screw pull through (3/9 DCP; 1/9 PLS), plate bending (2/9 DCP; 6/9 PLS) and scapular bone bending or fracture (4/9 DCP; 2/9 PLS). There was no significative difference between DCP and PLS (Fisher's exact tests).

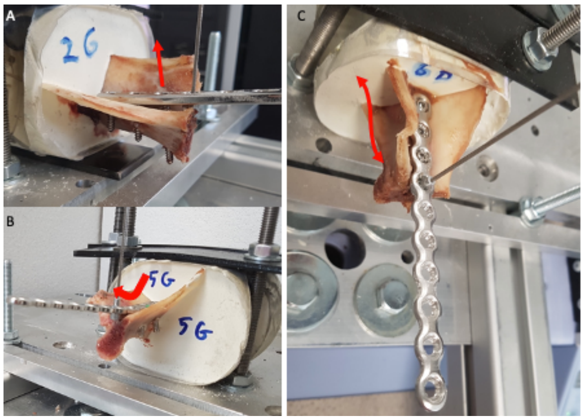

Figure 1. Modes of failure: (A) DCP pull through, (B) PLS plate bending, (C) PLS scapula bending.

No significative difference was found in load to failure and linear stiffness (Table 1) between DCP and PLS construct (one-way ANOVA, $p=0.60$ and $p=0.27$). We also found no significative difference in linear stiffness depending on the failure mode (one-way ANOVA, $p=0.76$). The failure load was significatively different between scapula bending/fracture and the others failure modes (one-way ANOVA $F=15.1$, followed by post hoc Tukey test $p<0.001$).

Table 1. Load of failure and linear stiffness results

	Failure Load N Mean (SD)	Linear Stiffness N/mm Mean (SD)
Implant type		
DCP	724 (223)	175 (43)
PLS	776 (192)	153 (40)
Failure mode		
Pull through	834 (59)	178 (44)
Plate	878 (123)	162 (35)
Scapula	522 (152) *	157 (54)

* significative difference
one-way ANOVA $F=15.1$, post hoc Tukey test $p<0.001$

Subjective differences in mode of failure could be explained by the differences between locking and compression plate. PLS plates have a more elaborate design making easier the contouring while preserving the locking mechanisms but this could lead to more plate bending given the good anchorage of the screws.

In this study Scapula bending or fracture happened more often in DCP and for thin scapulae. However, this mode of failure is uncommon in clinical cases and might be the consequence of a shoulder abduction when both humerus and scapula are implanted.
Even if the load at failure is significatively different, it is considered high enough not to be a relevant clinical concern.

4. Conclusions

We did not find any significative difference in pull out strength and linear stiffness between 3.5mm DCP and PLS constructs in our ex vivo model. At high values of strength, we observed more plate bending with PLS while we observed more screw pullout and scapula defects with DCP.
Canine scapular PLS construct seems to offer a stability at least as good as with DCP when implanted in the context of shoulder arthrodesis. More investigations including cyclic testing are required before concluding on the clinical relevance in the dog.

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