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Load System of Segmental T-Loops for Canine Retraction

Zeyang Xia^a, Jie Chen^{b,c}, Feifei Jiang^b, Shuning Li^b, Rodrigo F Vieceilli^d, and Sean Y. Liu^c

^aShenzhen Institutes of Advanced Technology, Chinese Academy of Sciences and The Chinese University of Hong Kong

^bDepartment of Mechanical Engineering, Indiana University Purdue University Indianapolis

^cDepartment of Orthodontics and Oral Facial Genetics, Indiana University

^dDepartment of Orthodontics, New York University College of Dentistry

Abstract

Objectives—The orthodontic load system, especially the ideal moment-to-force ratios (M/F), is the commonly used design parameter of segmental T-loops for canine retraction. However, the load system, including M/F, may be affected by the changes in canine angulations and interbracket distance (IBD). Here, we hypothesize that clinical changes in canine position and angulation during canine retraction will significantly affect the load system delivered to the tooth.

Methods—The load systems of two T-loop groups, one for translation (TR) and the other for controlled tipping (CT), from nine bilateral canine retraction patients were made to the targeted values obtained from finite element analyses and validated. Each loop was tested on the corresponding maxillary dental cast obtained in the clinic. The casts were made before and after each treatment interval so that both initial and residual load systems could be obtained. The pre- and post-treatment IBDs were recorded for calculating IBD changes.

Results—As the IBDs decreased, the averaged retraction-force-drop per IBD reduction was 36 cN/mm, a 30% drop per 1 mm IBD decrease. The averaged anti-tipping-moment-drops per IBD reductions were 0.02 N-mm/mm for CT and 1.4 N-mm/mm for TR, ~0.6 % and 17% drop per 1 mm IBD decrease, respectively. Consequently, the average M/F increases per 1 mm IBD reduction were 1.24 mm/mm for CT and 6.34 mm/mm for TR. There was significant residual load left, which could continue to move the tooth if the patient missed the scheduled appointment.

Conclusions—Clinical changes in canine position and angulation during canine retraction significantly affect the load system. The initial planned M/F needs to be lower to reach the expected average ideal value. Patients should be required to follow the office visit schedule closely to avoid negative effects due to significant M/F increases with time.

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Corresponding author: Jie Chen, PhD, Professor and Chair, Department of Mechanical Engineering, Professor, Department of Orthodontics and Oral Facial Genetics, Indiana University Purdue University Indianapolis, 723 W. Michigan St. SL260, Indianapolis, IN 46202, U.S., Tel: 317-274-5918, Fax: 317-274-9744, jchen3@iupui.edu.

Conflict of interest statement

The authors indicate no potential conflicts of interest.

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Introduction

Segmental T-loops are used in maxillary canine retraction. The resulting orthodontic load (force and moment) system on the canine is affected by multiple factors, including changes in interbracket distance (IBD) and tooth angulations.¹⁻³ However, the changes in the clinical load system that occurs simultaneously with canine movement have not been quantified. Different load system, especially small difference in moment-to-force ratios (M/F), results in different tooth movement patterns, in terms of tipping and/or translation.^{4,5} It is important to quantify the load changes for predicting the treatment effects and avoiding potential side-effects. Here, we hypothesize that clinical changes in canine position and angulation during canine retraction will significantly affect the load system delivered to the tooth.

An orthodontic load system is three-dimensional (3D), which consists of three force and three moment components. It is difficult to measure the entire 3D orthodontic load system clinically. Therefore, it has been investigated primarily on laboratory settings using archwires placed on dental casts,⁶⁻⁸ using numerical estimation, such as the LOOP simulation software⁹⁻¹² or the finite element (FE) method.^{13,14} Viecilli (2006) simulated the effect of changes in positions of the canine position and angulation on the M/F. The study was 2D and based on ideal rotation.¹² Despite clinically applicable information acquired, these studies were mostly conducted on ideal dentures, and changes of the load systems of individual patients during tooth movement have not been considered.

In order to better understand how the load system affects tooth movement clinically, the load components and their changes during clinical treatment need to be quantified. The objectives of this study were to monitor the clinical load systems on the canines undergoing retraction, and quantify the effects of its movement pattern on the load components.

Method

Customized segmental T-loops were designed and fabricated to retract canines with tipping or translation. Measurements of force and moment components, and the M/F were performed using models obtained from the patient at different time-points, and a custom made orthodontic force tester. IBDs and initial and residual load components before and after canine retraction were quantified to investigate changes of the load system during canine retraction.

After approved by the Institutional Review Board, nine patients were consented and recruited in this study. The inclusion criteria were 1) necessity of extraction of both maxillary 1st premolars and 2) a possible indication for maxillary canine retraction during treatment. The average age of patients was $21 \pm$ years old (ranging from 14 to 47 years old). The maxillary 1st premolars were extracted and the upper dental arch including the 2nd molars was bracketed, leveled, and aligned with sequential archwires. Prior to the canine retraction, a .019×.025-inch stainless steel archwire was fully engaged in the .022×.028-inch slot sized brackets. The maxillary 2nd premolar, 1st molar, and 2nd molar were co-ligated with a .010 stainless steel wire, connected with a transpalatal arch to establish a posterior unit.

For each patient, the right and left canines were randomly assigned to receive controlled tipping (CT) or translation (TR) orthodontic tooth movements. To accomplish CT or TR, two segmental T-loops, made of 0.017 × 0.025 TMA wire (Ormco, Glendora, CA), were designed and fabricated to deliver different M/F to retract canines. The T-loops on both sides were designed to deliver 124 cN of retraction force.¹⁵ The desired M/F ratios for CT and TR were calculated using finite element (FE) models of the patients, constructed based on cone beam computed tomography (CBCT). The CBCT maxillary image was taken prior

to canine retraction using I-CAT (Imaging Sciences International, LLC, PA) at the resolution of 0.25 mm voxel size with scanning time of 27 seconds. For each patient, the raw image data of CBCT scan were processed using MIMICS® (Materialise Group, Leuven, Belgium) software to create a reconstructed digital model of the teeth, periodontal ligament (PDL), and maxillary bone complex. A FE model was created from the digital model and then imported into ANSYS (Canonsburg, PA) software to compute tooth displacement due to an orthodontic load. The load consisted of the retraction force, F , and a couple, C , (moment), which were applied at the bracket (Fig. 1). The resulting tooth displacement pattern was calculated. The moment was then incrementally increased. The moment and force pairs that create translation and controlled tipping were identified. The details of the modeling were reported previously.¹⁶ The average desired M_x/F_y of the 9 patients for CT was 7.7 mm and for TR was 10.4 mm.

The IBD was defined as the distance from the mesial aspect of the auxiliary tube of the 1st molar bracket to the distal aspect of the canine bracket. This IBD was expected to decrease during canine retraction and, with it, there would be more decrease in force than moment, resulting in an M/F increase. For this reason, measures for initial M/F adjustment needed to be conducted. The M/F increase in the retraction plane per 1 mm IBD reduction was estimated using the LOOP (Kifissia, Hellas, Greece) simulation software. An approximate 50% M/F increase was estimated per 1 mm IBD reduction from this analysis. In this study, each treatment period was defined as when a canine was retracted more than 1 mm, which was measured during each office visit. The IBD changes were expected to vary significantly because of variation in treatment time period due to scheduling related issues. Thus, the total M/F increase could only be estimated, which was set at 70%. To be consistent, the calculated M/F for translation was decreased by approximately 35% (half of the estimated total M/F increase) to ensure that the average M/F during the treatment period was close to the ideal value. The M/F for tipping was further discounted to enhance tipping effects. In addition, in order to prevent mesial-out rotation caused by the retraction force, the desired anti-rotation moment for translating the tooth was also calculated using the same FE model. To ensure the average M_z/F_y ratio to be close to the desired value, the implemented initial M_z/F_y was reduced by approximately 35% on both canines to compensate the effects of IBD reduction. However, the target M_z/F_y was difficult to achieve because it was primarily realized by adjusting the 1st order gable angles. Large gable angles were required in many cases, which caused the T-loop to interfere with the cheek or gum. To avoid interference, only smaller gable angles could be introduced, which caused M_z to be lower than the target value. The main focus of this study was on translation and tipping. The control of M_z was considered secondary and thus was allowed to be compromised in some cases. Other load components were kept minimal when the T-loops were produced.

According to the desired load system, the T-loops were bent to express desired force and moment components. These components were calibrated experimentally on the corresponding dental casts. The casts were prepared using the following protocol. Over the period of canine retraction, patients were seen every 5–6 weeks. A decision was made on whether a treatment interval was completed. A treatment interval was defined when one canine moved more than 1 mm. Thus, multiple intervals might occur for each patient because all patients in this study had more than 3 mm space between the canine and the 2nd premolar. However, the number of intervals varied among the patients due to the difference in tooth movement rate and duration between office visits. When an interval was completed, an impression was made, the T-loop was retrieved, and a new T-loop was designed and applied. Then the next treatment interval began. The casts were made before and after each interval. At the beginning of each treatment interval, each T-loop was adjusted on the corresponding duplicate acrylic model attached to a custom-made orthodontic force tester (OFT)⁶ to ensure delivering accurate loads. Impression of upper dental arch was made by

injecting light and medium-body polyvinylsiloxane (PVS) material (Examix NDS, GC Corporation, Tokyo, Japan) over the brackets, followed by alginate impression. Duplicate canine and first molar brackets with tubes (Burstone TM,Ormco, Glendora, CA) were placed in the PVS and autopolymerizing acrylics (Repair Material, Dentsply, York, PA) were packed into the impression and allowed to cure. The acrylic model was attached to the OFT with two screws. The target teeth (canines) were attached to the load cells with epoxy adhesive (Loctite E-120HP Hysol Epoxy Adhesive, Henkel, Rocky Hill, CT) and then were completely separated from the acrylic model, thus maintaining their original positions and orientations (Fig. 2).

After measuring the initial IBDs between the canine and molar tubes of the acrylic model, a T-loop was made with the geometry shown in Fig. 3. The size, shape, leg length, and dimensions of T-loops were determined considering their effects on the load system,² as well as avoiding interference with the cheek and gum. The first and second order gable bends were added symmetrically to the T-loops to bring the load components to the targets, Fig. 4. The loop bending and adjustment process was iterated until the desired force and moments were accurately expressed. The horizontal leg was bent on each end of the T-loop to allow easy insertion into the tube, which also ensured that the IBD was identical when transferred the OFT validated T-loop to the patient, Fig. 5. The validation was performed on the OFT. T-loops were installed on the duplicate acrylic model attached to the OFT for testing force and moment components. The OFT was designed to measure the orthodontic load system at the canine's bracket (Fig. 2a). Two load cells (Multiaxis force/torque Nano17, ATI Industrial Automation, Apex, NC) were used to measure the six force and moment components applied at the canine brackets. The force range of each load cell is 0–20 N with a 0.025 N resolution and the moment range is 0–100 N-mm with a 0.003 N-mm resolution. A local coordinate system was established on each left canine with the retraction direction aligned with the load cell's positive y axis, the buccal direction with the positive x axis, and the gingival direction with the positive z axis (Fig. 2b). The local coordinate system on the right canine was different from the left canine (Figs. 2a and 2b). In this study, the clinically expressed load systems were of interest and the side was not a controlled parameter because tipping or translation was randomly assigned to each side. Thus, the clinically used coordinate system on the left side was used to describe the results.

For each treatment interval, an acrylic model was fabricated after each treatment period and a new T-loop was bent for each canine and adjusted using the OFT. The post-treatment IBDs were also recorded. The T-loops used in the previous treatment were retrieved and installed on the post-treatment acrylic model to measure the residual load system using the OFT. The T-loops retrieved were examined visually for signs of permanent deformation or other damages due to removal. The damaged T-loops were excluded from this study. Consequently, both initial and residual load systems were recorded.

Linear regressions were performed on the retraction force, F_y , drop, anti-tipping moment, M_x , drop, and M_x/F_y increase with respect to IBD changes, respectively. The initial and residual load systems were compared using paired t-test. The force and moment drops between the CT and TR groups were compared using a t-test. Significance was tested at 95% confidence level.

To assess the errors due to wire installation and instrument, a cast and a T-loop were used for a repeatability test. The same T-loop was installed on the same cast ten times. The resulting load system corresponding to each installation was measured. The mean and standard deviation were calculated.

Results

The installation and instrument errors of the six load components were shown in Table 1. The maximum standard deviations for the key load components, F_y , M_x , and M_z are only 1%, 1%, and 3% respectively, meaning that the measurements are consistent.

Only 9 T-loops on the CT side and 11 T-loops on the TR side passed the visual inspections. The initial IBDs in this study ranged from 16.4 to 24.4 mm because of interpersonal difference or variation in incremental tooth displacement. The IBD decrease in each treatment interval ranged from 0.3 to 1.9 mm (1.23 mm in average). Despite of the 1 mm canine movement criterion for the treatment interval, there were intervals with larger canine movements, causing larger IBD decreases. The larger decrease was primarily due to prolonged treatment interval caused by missed appointments. The initial and residual load systems were measured, Table 2. The load systems on both sides were expressed following the same convention. The positive y axis corresponds to the retraction (distal) direction, the positive x represents buccal direction, and the positive z axis corresponds to gingival direction. The positive M_x tips the crown distally, positive M_y tips the crown lingually, and the positive M_z rotates the crown distal-in. Thus, $-M_x$ is the anti-tipping moment. The initial retraction force, F_y , was 124.4 ± 3.3 cN. On the retraction plane, the initial anti-tipping moment, M_x , was -780 ± 0.8 cN-mm for TR and -340 ± 1.1 cN-mm for CT. Consequently, the initial M_x/F_y was -6.3 ± 0.8 mm for TR and -2.8 ± 0.9 mm for CT after implemented the M/F discounts described in Method. The M_z/F_y was not reported because M_z was compromised to avoid interference with the cheek and gum.

The load systems between the two groups were compared first. Statistically, there was no significant difference in the force drops ($p=0.4046$), but has significant difference ($p=0.02037$) in moment drops between the CT and TR groups. The retraction force dropped to 58.5 ± 20.6 cN (residual force) on the CT side and to 55.6 ± 26.6 cN on the TR side at the end of each treatment interval. The average initial anti-tipping moment, M_x , drop on the CT side was 140 ± 130 cN-mm, which decreased to -200 cN-mm (residual moment); on the TR side was 250 ± 150 cN-mm, which dropped to -530 cN-mm. Consequently, the average M_x/F_y drop on the CT side was 1.1 ± 2.3 mm; on the TR side was 4.0 ± 3.6 mm. In the other directions, like the retraction force, the initial load components were the same, thus the data of the two groups were combined. The buccal-lingual force, F_x , changed from -5.6 ± 17.5 cN (lingual) to 9 ± 24.9 cN (buccal); the occlusal-gingival force, F_z , from 4.7 ± 11.9 cN to 3.4 ± 17.9 cN (intrusion); anti-tipping moment, M_y , in buccal-lingual direction from 60 ± 180 N-mm to 50 ± 180 cN-mm (lingual tipping); and anti-rotation moment, M_z , from -580 ± 190 cN-mm to -520 ± 240 cN-mm (crown mesial-in).

The retraction forces, F_y , were decreased as the IBD was reduced due to canine retraction. Fig. 6 shows the IBD reduction versus force drop of each loop. The linear regressions of force drop vs. IBD change for the two groups were estimated as:

$$\begin{aligned}\text{CT: } F_y \text{ drop (cN)} &= 35.3 + 26.7 \times \text{IBD reduction (mm)} \\ \text{TR: } F_y \text{ drop (cN)} &= 14.9 + 44.9 \times \text{IBD reduction (mm)}\end{aligned}$$

The averaged retraction force drop per IBD reduction on the CT side is 26.7 cN/mm and on the TR side is 44.9 cN/mm, meaning after 1 mm IBD decrease the retraction force has dropped by 20% on the tipping side and 36% on the translation side from the initial values ($P < 0.0001$), respectively. The coefficients of determination (R^2) were 0.3714 and 0.5575. This coefficient is between 0 and 1, the higher the value the stronger the correlation is.

Similarly, the anti-tipping moment, M_x , was also reduced with decreasing IBD (Fig. 7). The linear regressions of anti-moment drop versus IBD reduction were expressed as:

$$\text{CT: } M_x \text{ drop (cN-mm)} = 134 + 2.1 \times \text{IBD reduction (mm)}$$

$$\text{TR: } M_x \text{ drop (cN-mm)} = 72 + 144 \times \text{IBD reduction (mm)}$$

The coefficients of determination were $R^2 = 0$ for CT and 0.1899 for TR, respectively. The averaged anti-tipping moment drop per 1 mm IBD decrease was about 2 cN-mm/mm for CT and 144 cN-mm/mm for TR, an 18% drop per 1 mm IBD decrease.

In contrast, M_x/F_y ratio increased with the reduction in IBD (Fig. 8). The linear regressions of anti-moment drop versus IBD reduction were expressed as:

$$\text{CT: } M_x/F_y \text{ increase (mm)} = -0.35 + 1.25 \times \text{IBD reduction (mm)}$$

$$\text{TR: } M_x/F_y \text{ increase (mm)} = -3.33 + 6.34 \times \text{IBD reduction (mm)}$$

The coefficients of determination were $R^2 = 0.063$ and 0.4836, respectively. The averaged M/F increase per IBD decrease is 1.25 mm/mm for CT and 6.34 mm/mm for TR.

Discussion

This clinical study quantified the orthodontic load-system of a T-loop segmental wire for canine retraction as well as its residual load-system as a function of IBD reduction due to canine movement. Our in-vitro “transfer” method, simulating the clinical condition, provides the best estimates at present on the clinical load systems because it preserves the boundary conditions that occur in the clinic, which are the dominating factors affecting the accuracy.⁶ The effects of bracket’s translation and rotation in all three directions were considered, which has never been done before. Although these results are limited for this type of T-loop, they have a broader implication because they express changes that could occur with loops with dimensions and activations calibrated to deliver similar load systems.¹⁷

The load systems on the canines were controlled and quantified, with the same retraction force and different anti-tipping moments in the retraction plane for either CT or TR. There were no significant differences in retraction force, F_y , drop vs. IBD decrease between the CT and TR groups. Thus, the F_y data was combined for further analyses. The averaged retraction-force-drop per IBD decrease was 36 cN/mm, a 30% drop per 1 mm IBD decrease ($P < 0.0001$). The anti-tipping moment, M_x , drops vs. IBD decrease were significantly different between the two groups, likely because the initial moments were different. The rate of M_x drop per IBD change is higher for TR than CT. TR requires a higher moment, which indicates that the M_x drop depends on the initial moment level. The higher the initial moment, the faster it drops. When the initial moment is low, there is a negligible moment drop, Figs. 7a and 7b.

Canine retraction causes both retraction force, F_y , and anti-tipping moment, M_x , to drop. (Figs. 6 and 7) IBD is directly related to canine retraction, but is not the only dominant factor affecting the force and moment drops. The coefficient of determination of regression analysis on IBD reduction vs. force drop indicated that there is some relationship between IBD and force drop. Coefficient of determination indicates the amount of variability in force drop explained by IBD decrease. The coefficient of determination for moment drop vs. IBD decrease on the TR side was only 0.1899, meaning that IBD decrease only explains 18% of the variability in moment drop. Theoretically, if the displacement only occurs in the retraction plane and there is no bracket angulation change due to tipping, the M/F change

should have little variation and the coefficient of determination should be high. However, in the clinic, the canine moves in 3D, which causes the bracket to rotate about all three axes. Consequently, other factors, such as bracket angulation, also contribute to the moment change, which create the significant scattering of the data in Fig. 7.

In this clinical study, there were large initial and residual out-of-retraction-plane load components, such as F_x , M_y and M_z in Table 1, which might initiate out-of-retraction-plane displacements and affect the final tooth position, including bracket angulation. These initial out-of-retraction-plane load components are difficult to eliminate for T-loop design. The values are non-trivial, thus need to be considered. To understand their effects on the load component drops, the six components of clinical displacement will need to be further studied.

Ideally, the load drops are expressed with the 3D tooth displacement, which includes angulation changes measured from the tooth's tipping and rotation. This ensures that coupling effects of angulation change in three directions are considered, which reflects the clinical reality. Previous studies^{18,19} measured 2D distal tipping angles from radiography and input the angles into computer models to calculate the residual load. The residual load was under ideal boundary conditions and the effects of angulations in the other two directions were not included. Although the results were more consistent, they might not accurately represent reality and did not reflect interpersonal variations. Thus, the results can be used only qualitatively. These issues were addressed in this study. However, the 3D displacement components are hard to measure clinically and difficult to present. Only IBD is directly measurable clinically, thus it is used in this study.

The results showed that, as the canine retracted, both retraction force and anti-tipping moment decreased at different rates. The load drop was significant (30% reduction per 1 mm IBD loss) and faster than the anti-tipping moment (0.6% and 18% reduction per 1 mm IBD loss for CT and TR, respectively). This differential drops between load and anti-tipping moment increases M/F. Our results support the previous findings¹⁷ that the anti-tipping moment, M_x , is less affected by the IBD change than the retraction force, although the increasing rate is different due to different T-loop designs. The tooth displacement pattern relies on the M/F. Prolonged treatment due to missing appointments will continue to increase the M/F, meaning applying a relative stronger anti-tipping moment than needed for translation. If this reaches a critical level, it may result in canine crown tipping on the mesial direction. Unless this is a desired tooth movement pattern, the patient may be strongly advised to keep the scheduled office visit and have the T-loop adjusted close to the scheduled time. On the other hand, if a higher anti-tipping moment is not achievable clinically, having a longer visit may achieve the desired M/F for TR as long as the residual retraction force is still effective.

Current theory requires that certain M/F to be maintained to either translate or tip the canine depending on the treatment strategies. This is difficult to achieve for segmental T-loop because the M/F changes as the tooth moves. Our results show the level of changes, which are significant to make clinical impact. To ensure the average M/F is close to the desired value, the initial M/F needs to be reduced depending on the expected tooth displacement in each treatment period. If the expected tooth displacement is 1 mm, then the initial M/F for translation should be about 3 mm less than the expected value because the M/F drop is about 6 mm per 1 mm IBD reduction. The more the expected tooth movement, the more M/F reduction is needed.

The initial retraction force should not be too low. It is commonly accepted that there is an effective force level for moving individual tooth, although there was no consensus on the

actual level. An initial force less than 36 cN would drop below zero when the canine retracts more than 1 mm, which would have no retraction effect. On the other hand, if the initial load is as high as 124 cN, like in our case, the retraction force would still be greater than the effective force level at the end of the predetermined treatment period, thus the tooth would still move if the patient misses the appointment. This force combined with the less dropped anti-moment would cause M/F to increase and exceed the value for TR, causing tipping on the protraction direction, a side-effect to avoid. Therefore, clinician may want to take this into consideration when determining the initial force level and scheduling the office visit.

Conclusion

A 3-D approach to calibration of customized segmental T-loops with desired loadings and measurement of change of loadings was developed and validated in a canine retraction clinical study. The following conclusions were made.

1. Clinical changes in canine position during canine retraction can significantly affect the load system delivered to the tooth.
2. In canine retraction, the retraction force decreases faster than the anti-tipping moment, which results in an M/F increase.
3. Out-of-retraction-plane load components exist and change, which will affect out-of-retraction-plane movement.
4. The initial M/F ratios need to be lower than the targeted value to reach the expected effect. The reduction can be approximately $\frac{1}{2}$ of the expected M/F increase during the treatment interval.
5. The initial force needs to be higher to ensure that the residual force is effective during the treatment period. The value depends on the force drop corresponding to the level of expected tooth movement.

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Fig. 1.

The finite element model of a canine-PDL-bone complex for estimating the M/F required to translate or tip the canine. A force, F , and a couple, C , were applied at the location of the tube on the bracket. The resulting tooth displacement was calculated. The F and C pairs that produced translation and controlled tipping were selected.

Fig. 2.

(a) The laboratory setting for measuring orthodontic load system on the canines. The setting includes an orthodontic force tester, a dental cast with brackets, and the T-loops. The coordinate systems on the left-side (b) and right-side (c) were defined at the centers of the canine brackets.

Fig. 3.
The geometry and dimensions of the loops before the first and second order bend were added

Fig. 4.
The fabricated T-loops

Fig. 5.
A canine retraction case with the T-loop on the left side

(a)

(b)

Fig. 6.

IBD decrease versus force drop of each loop, (a) on the controlled tipping side and (b) on the translation side

(a)

(b)

Fig. 7. IBD decrease versus moment drop of each loop, (a) on the controlled tipping side and (b) on the translation side

(a)

(b)

Fig. 8.

IBD decrease versus M/F increase of each loop, (a) on the controlled tipping side and (b) on the translation side

Table 1

The results from the test to estimate errors due to T-loop installation and instrument

Num	Fx (N)	Fy (N)	Fz (N)	Tx (N-mm)	Ty (N-mm)	Tz (N-mm)
1	-0.28	1.16	0.21	-6.95	-3.32	-5.10
2	-0.29	1.18	0.23	-6.93	-3.29	-4.88
3	-0.29	1.19	0.25	-6.81	-3.22	-4.77
4	-0.30	1.17	0.26	-6.70	-3.54	-4.63
5	-0.29	1.17	0.25	-6.80	-3.49	-4.67
6	-0.30	1.14	0.23	-6.92	-3.56	-4.64
7	-0.28	1.17	0.23	-6.86	-3.23	-4.90
8	-0.28	1.17	0.25	-6.70	-3.47	-4.70
9	-0.29	1.15	0.25	-6.78	-3.47	-4.71
10	-0.28	1.17	0.26	-6.66	-3.41	-4.74
Mean	-0.29	1.17	0.24	-6.81	-3.40	-4.77
SD	0.01	0.01	0.02	0.10	0.12	0.15

Table 2

The means and standard deviations of the load components on the controlled tipping side, on the translation side, and on both sides combined

	Status		Ex	Fy	Fz	Mx	My	Mz	Mx/Fy
			cN	cN	cN	cN-mm	cN-mm	cN-mm	cN-mm
CT	Initial	Mean	-1.22	123.00	2.67	-340	81	-519	-2.74
		SD	15.64	2.35	16.12	110	112	202	0.91
	Residual	Mean	9.11	57.33	6.22	-203	-3	-490	-3.81
		SD	31.70	22.56	19.80	120	157	211	2.62
TR	Initial	Mean	-9.09	125.55	6.36	-779	043	-629	-6.22
		SD	18.90	3.67	7.34	81	218	166	0.78
	Residual	Mean	8.91	52.09	1.00	-522	86	-551	-11.11
		SD	19.31	24.68	16.80	157	195	274	3.61
Combined	Initial	Mean	-5.55	124.40	4.70	-582	60	-580	-4.66
		SD	17.53	3.33	11.89	242	175	187	1.95
	Residual	Mean	9.00	54.45	3.35	-379	46	-524	-7.83
		SD	24.89	23.28	17.91	213	180	243	4.86