Editorial Manager(tm) for Spine Journal
Manuscript Draft

Manuscript Number: SPINE 090587

Title: Prediction of Scoliosis Correction with Thoracic Segmental Pedicle Screw Constructs using Fulcrum Bending Radiographs

Article Type: Clinical Case Series

Keywords: Fulcrum bending radiograph; scoliosis correction; thoracic pedicle screw.

Corresponding Author: Dr. Wai Yuen Cheung, MD

Corresponding Author's Institution: Queen Mary Hospital

First Author: Wai Yuen Cheung, MD

Order of Authors: Wai Yuen Cheung, MD; Lawrence G Lenke, MD; Keith DK Luk, MD

***Title Page**

Prediction of Scoliosis Correction with Thoracic Segmental Pedicle Screw Constructs using Fulcrum Bending Radiographs

Authors:

WY Cheung[1], FRCSE, FHKAM

Lawrence G. Lenke[2], MD

KDK Luk[1], FRCSE, FHKAM

[1] Department of Orthopaedics and Traumatology, The University of Hong Kong, Hong Kong, China

[2] Washington University School of Medicine, St. Louis, MO USA

Investigation performed at Washington University School of Medicine

Corresponding Author:

WY Cheung, FRCS, FHKAM
Tel: (852) 28553825
Fax: (852) 28174392
E-mail: lcheung@hkucc.hku.hk

*Structured Abstract (300 words)

Abstract

Study design: A retrospective series of 35 idiopathic scoliosis patients underwent spinal fusion with a segmental thoracic pedicle screw system.

Objective: To evaluate the amount of scoliosis correction with segmental pedicle screw constructs and assess whether the fulcrum bending radiograph can predict surgical correction.

Summary of Background Data: The fulcrum bending radiograph is highly predictive of actual curve correction based on hook or hybrid systems. However, its predictive value in segmental pedicle screw fixation systems has not been reported.

Methods: Patients diagnosed with Lenke type 1A and 1B thoracic idiopathic scoliosis who underwent posterior spinal fusion with segmental pedicle screw constructs by single surgeon from January 2000 to December 2005 were reviewed. The fulcrum flexibility rate (FFR) and correction rate (CR) were compared. Stepwise linear regression analysis was done and a prediction equation for the postoperative Cobb angle was developed.

Results: Thirty-five consecutive patients were included. Age at surgery was 14.8 years. Twenty scoliosis deformities were flexible, fifteen were rigid. All patients had at least 2-year follow up. The average preoperative Cobb angle was 58º, fulcrum bending Cobb angle was 28º and postoperative Cobb angle 15º and 16º at 1 month and 2 years respectively after surgery. There was significant difference between FFR (51%) and CR at 1 month (72%) and 2 year (70%) after surgery. The difference between fulcrum bending corrective index (FBCI) of flexible (127%) and rigid (187%) curves was statistically significant. Stepwise linear regression analysis showed: Predicted postoperative Cobb angle = 0.012 + 1.75 x age – 0.212 x FFR. ($R=0.69$, $P<0.01$)

Conclusion: Thoracic pedicle screw constructs achieved better scoliosis correction compared with fulcrum bending radiographs. The FBCI achieved was significantly greater in rigid than flexible curves. The post-operative Cobb angles could be calculated with a predictive equati

*Key Points (3-5 main points of the article)

Key Points

Thoracic pedicle screw constructs could achieve better scoliosis correction compared with the fulcrum bending radiograph.

The fulcrum bending corrective index was greater in rigid than flexible curves.

The post-operative Cobb angle could be calculated with an equation.

*Mini Abstract (50 words)

Mini Abstract

A review of 35 consecutive patients suffered from idiopathic scoliosis showed segmental thoracic pedicle screw constructs achieved better scoliosis correction compared with fulcrum bending radiographs. The fulcrum bending corrective index was significantly higher in rigid than flexible curves. The post-operative Cobb angles could be calculated with a predictive equation.

*Manuscript Text (must include page numbers)

Prediction of Scoliosis Correction with Thoracic Segmental Pedicle Screw Constructs using Fulcrum Bending Radiographs

Introduction

The flexibility of structural curves in adolescent idiopathic scoliosis (AIS) is an integral part of the preoperative planning process and directly influences the selection of levels to be fused as well as indicating the degree of surgical correction that may be expected. It can also dictate if an additional surgical release or osteotomy is necessary to gain optimal reduction of the deformity.[1]

Various methods have been described to assess flexibility of scoliosis deformities including active side bending radiographs[2-4], push-prone radiographs[5,6], supine traction radiographs[7] and fulcrum bending radiographs.[8] The fulcrum bending radiograph is attractive, as the patient does not need to actively participate in the examination. This is advantageous in patients who are unable to completely follow instructions, such as children or those with intellectual impairment. The correcting force of a fulcrum bending radiograph depends on the patient's body weight so it is constant and reproducible. It also does not expose medical personnel to radiation when applying correcting forces during radiographic examination.

Luk and Cheung[8] found that correction achieved on the fulcrum bending radiograph was highly predictive of actual curve correction via posterior instrumentation with hook systems for patients diagnosed with idiopathic scoliosis. They also compared the power of scoliosis correction with different instrumentation systems in terms of the fulcrum bending corrective index derived from the fulcrum bending radiograph.[9] Recently, the fulcrum bending radiograph was also shown to be useful in determining the levels to be included in spinal fusion for patients with thoracic idiopathic scoliosis.[10] However, all of these studies were based on hook or hybrid systems for posterior spinal fusion.

Pedicle screw fixation is gaining popularity in scoliosis surgery. With three-column control of the vertebrae and segmental anchorage points, it should achieve better deformity correction compared with hook or hybrid systems. Our study reviewed the amount of curve correction in patients diagnosed with thoracic adolescent idiopathic scoliosis that underwent posterior spinal fusion with a segmental pedicle screw fixation system and assessed whether the fulcrum bending radiograph can predict the amount of surgical correction.

Methods

After institutional review board approval, a retrospective review of medical records and radiographs of patients diagnosed with thoracic idiopathic scoliosis who underwent posterior spinal fusion with instrumentation at two different Children's hospitals by the senior author, from January 2000 to December 2005 was done. AIS patients with Lenke type 1A and 1B curves, with preoperative fulcrum bending radiographs taken and treated with posterior spinal fusion with segmental pedicle screw constructs (pedicle screws at every vertebral level of the fusion segment) were included in the study (fig 1). Patients diagnosed with non-idiopathic scoliosis, requiring additional osteotomy or surgical release were excluded from the study. Fulcrum bending radiographs were obtained as described by Cheung and Luk[7] by laying the patient in the lateral decubitus position over a radiolucent fulcrum. The location of the fulcrum was at the rib of the corresponding apex of the curve.

Cobb angles on preoperative standing, preoperative fulcrum bending and 1-month and 2 years postoperative standing radiographs were measured and compared with paired t-test. A P value of less than 0.05 was regarded as statistically significant.

The fulcrum flexibility rate (FFR) was defined as[8]

$$\frac{\text{Preoperative Cobb angle} - \text{Fulcrum bending Cobb angle}}{\text{Preoperative Cobb angle}} \times 100\%$$

The correction rate (CR) was defined as[8]

$$\frac{\text{Preoperative Cobb angle} - \text{Postoperative Cobb angle}}{\text{Preoperative Cobb angle}} \times 100\%$$

The FFR and CR were compared with paired t-test. A P value less than 0.05 was regarded as statistically significant.

The fulcrum bending corrective index (FBCI) was defined as[8]

$$\frac{\text{Correction rate}}{\text{Flexibility rate}} \times 100\%$$

FBCI for rigid curves with an FFR less than 50% and flexible curves with an FFR more than 50% were compared with one sample t-test.

Correlations between the postoperative Cobb angle with patient's age, preoperative Cobb angle, fulcrum bending Cobb angle and fulcrum flexibility rate were assessed with Pearson Correlation. Stepwise linear regression analysis was done with the postoperative Cobb angle as the dependent variable; and the patient's age, preoperative Cobb angle, fulcrum bending Cobb angle, and fulcrum flexibility as the independent variables. A prediction equation for the postoperative Cobb angle was developed.

Results

Thirty-five consecutive AIS patients with Lenke type 1A and 1B curves having preoperative fulcrum bending radiographs taken and who underwent posterior spinal fusion with segmental pedicle screw fixation were included in the study. All surgeries were performed by the senior author using 5.5-mm stainless steel rod based segmental Cotrel-Dubousset Horizon Instrumentation System (Medtronic, Memphis, TN). All pedicle screws were inserted via the free hand technique. Deformity correction was achieved with rod rotation and direct apical derotation. All patients had at least 2-year follow-up. Twenty-eight patients were female (80%) and 7 were male (20%). Twenty (57%) scoliosis deformities were flexible and 15 (43%) were rigid. Age at surgery was 14.8±1.8 years. Twenty-six patients (74%) had Lenke type 1A curves and 9 patients (26%) had type 1B curves (Table 1).

The average preoperative Cobb angle was 58º±8, fulcrum bending Cobb angle was 28º±9 and postoperative Cobb angle 15º±6 and 16º±7 at 1 month and 2 years respectively after surgery. There was significant difference between fulcrum bending Cobb and postoperative Cobb angles ($P<0.05$) (table 2). The difference between postoperative Cobb angle at 1 month and 2 years after surgery was statistically insignificant.

The fulcrum flexibility rate was 51% compared to correction rates of 72% and 70% at 1 month and 2 years after surgery. The fulcrum bending corrective index at 1 month and 2 years postoperative was 152%±47 and 148%±47 respectively. The difference between fulcrum flexibility rates and correction rates at 1 month and 2 years postoperative was statistically significant ($P<0.05$). (Table 3)

A scatter plot of the fulcrum bending corrective index versus the fulcrum flexibility rate showed a negative relationship between the two parameters (fig 2). The fulcrum bending corrective index for flexible curves was 127%±15, and for rigid curve was 187%±52. The difference between the two groups was statistically significant (table 3).

Pearson correlation analysis showed that the postoperative Cobb angle is highly correlated with the patient's age (R=0.520, P<0.01), fulcrum bending Cobb angle (R=0.505, P<0.01) and fulcrum flexibility rate (R=0.506, P<0.01). There was no correlation between preoperative Cobb angles and postoperative Cobb angles (R=0.171, P=0.326). (Table 4)

Stepwise linear regression analysis showed:

Predicted postoperative Cobb angle = 0.012 + 1.75 x age – 0.212 x fulcrum flexibility rate.

(R=0.69, P<0.01)

Using the predictive equation, the predicted postoperative Cobb angle was 15º±4. The differences between the predicted and the actual postoperative Cobb angles were 0º±5 at 1 month and –1º±8 and 2 years postoperative respectively. There was no significant difference between the predicted Cobb angle and the actual postoperative Cobb angle at 1 month and 2 years after surgery. (Table 5)

Discussion

Using pedicle screws for thoracic idiopathic scoliosis was first described by Suk et al[11] in 1994. It can achieve three-column control of the vertebrae which allows better manipulation and correction of spinal deformity. The complete intraosseous placement of screws also minimizes direct implant infringement on neural elements during the surgical procedure. Various studies have also confirmed that using thoracic pedicle screw for scoliosis surgery is safe.[12,13]

In our study, the correction rate achieved with segmental thoracic pedicle screw constructs was 74%±11. It was significantly higher than the fulcrum flexibility rate of 52%±14. This finding concurs with previous studies showing that segmental pedicle screw constructs can provide better scoliosis correction compared with hook systems.[11,14] Suk et al[11] demonstrated a correction rate of 63% with screw systems compared with hook systems which demonstrated 49% rate of correction. Dobbs et al[14] reported correction rates with screw and hook constructs of 53% and 34% respectively.

The difference in Cobb angles at early and 2 years postoperative was on average 1-degree and statistically insignificant. It demonstrated that in addition to better scoliosis correction, pedicle screw constructs could also maintain correction. A similar finding was also reported by Dobbs.[14] He reported a 2-degree difference with screws compared with the 7-degree difference with hooks in Cobb angles between early and 2 years after surgery.

We found that the fulcrum bending corrective index with pedicle screw constructs decreased as the fulcrum flexibility rate increased. This finding though logical, has not been reported. For flexible scoliosis, most of the deformity was corrected with fulcrum bending, so no matter how strong the instrumentation system was, it could not achieve much correction beyond fulcrum bending. We divided the patients into two groups, flexible and rigid. The flexible group had a fulcrum flexibility rate of more than 50% and the rigid group with fulcrum bending flexibility was less than 50%. We also found that the fulcrum bending corrective index in the flexible group (127%±15) was significantly less compared with that of the rigid group (187%±52), which demonstrates that pedicle screw constructs are more beneficial in correcting rigid scoliosis than flexible curves.

We only included patients with Lenke type 1A and 1B curves in this study. This was because for patients with more than one structural curve, the flexibility of the curves is usually different and correction of one curve usually affects correction of the other. We excluded Lenke type 1C curves because many surgeons, including the senior author, deliberately under-correct the curve in order to achieve good trunk balance after surgery.[15] With this homogeneous group of patients, with a thoracic scoliosis deformity that the surgeon could safely correct as much as possible with the instrumentation system, we identified significant correlations between postoperative Cobb angles and preoperative parameters. We also excluded patients where intra-operative posterior osteotomies were performed to avoid entering another surgical variable which would be difficult to control. We found that the postoperative Cobb angle is highly correlated with the age of the patient at surgery (R=0.52, P=0.001), the fulcrum bending Cobb angle (R=0.505, P=0.002), and the fulcrum flexibility rate (R=–0.506, P=0.002). This is the first study which identifies correlations between the flexibility of the curves assessed before surgery and the postoperative Cobb angle of scoliosis patients treated with thoracic pedicle screw constructs. With stepwise linear regression analysis, a predictive equation was developed:

Predicted postoperative Cobb angle = 0.012 + 1.75 x age – 0.212 x fulcrum flexibility rate.

Using this predictive equation, the postoperative Cobb angle could be accurately calculated. There was no significant difference between the predicted and actual postoperative Cobb angles. The 95% confident interval difference between the predicted and actual postoperative Cobb angles was –2 to 4º. Such a predictive equation has not been previously reported.

Conclusion

Thoracic pedicle screw constructs achieve better scoliosis correction compared with fulcrum bending radiographs, which was well maintained at two years after surgery. The correction achieved is significantly greater in rigid curves versus flexible curves. The degree of correction achieved after surgery highly correlates with the patient's age, the fulcrum bending Cobb angle, and the fulcrum flexibility rate, which could be accurately calculated with a predictive equation.

References

1. Hamzaoglu A, Talu U, Tezer M, et al. Assessment of curve flexibility in adolescent idiopathic scoliosis. *Spine* 2005;30:1637–42.
2. Large DF, Doig WG, Dickens DR, et al. Surgical treatment of double major scoliosis. Improvement of the lumbar curve after fusion of the thoracic curve. *J Bone Joint Surg Br* 1991;73:121–4.
3. McCall RE, Bronson W. Criteria for selective fusion in idiopathic scoliosis using Cotrel-Dubousset instrumentation. *J Pediatr Orthop* 1992;12:475–9.
4. Vaughan JJ, Winter RB, Lonstein JE. Comparison of the use of supine bending and traction radiographs in the selection of the fusion area in adolescent idiopathic scoliosis. *Spine* 1996;21:2469–73.
5. Kleinman RG, Csongradi JJ, Rinsky LA, et al. The radiographic assessment of spinal flexibility in scoliosis: a study of the efficacy of the prone push film. *Clin Orthop Relat Res* 1982;162:47–53.
6. Vedantam R, Lenke LG, Bridwell KH, et al. Comparison of push-prone and lateral-bending radiographs for predicting postoperative coronal alignment in thoracolumbar and lumbar scoliotic curves. *Spine* 2000;25:76–81.
7. Polly DW Jr., Sturm PF. Traction versus supine side bending. Which technique best determines curve flexibility? *Spine* 1998;23:804–8.
8. Cheung KM, Luk KD. Prediction of correction of scoliosis with use of the fulcrum bending radiograph. *J Bone Joint Surg Am* 1997;79:1144–50.

9. Luk KD, Lu DS, Cheung KM, et al. A prospective comparison of the coronal deformity correction in thoracic scoliosis using four different instrumentations and the fulcrum-bending radiograph. *Spine* 2004;29:560–3.
10. Luk KD, Don AS, Chong CS, et al. Selection of fusion levels in adolescent idiopathic scoliosis using fulcrum bending prediction: a prospective study. *Spine* 2008;33:2192–8.
11. Suk SI, Lee CK, Min HJ, et al. Comparison of Cotrel-Dubousset pedicle screws and hooks in the treatment of idiopathic scoliosis. *Int Orthop* 1994;18:341–6.
12. Kim YJ, Lenke LG, Bridwell KH, et al. Free hand pedicle screw placement in the thoracic spine: is it safe? *Spine* 2004;29:333–42
13. Suk SI, Kim WJ, Lee SM, et al. Thoracic pedicle screw fixation in spinal deformities: are they really safe? *Spine* 2001;26:2049–57.
14. Dobbs MB, Lenke LG, Kim YJ, et al. Selective posterior thoracic fusion for adolescent idiopathic scoliosis: comparison of hooks versus pedicle screws. *Spine* 2006;31:2400–4.
15. Dobbs MB, Lenke LG, Walton T, et al. Can we predict the ultimate lumbar curve in adolescent idiopathic scoliosis patients undergoing a selective fusion with undercorrection of the thoracic curve? *Spine* 2004;29:277–85.

Table 1: Distribution of sex and curve types.

	Number of patients	Percentage of patients
Sex		
Female	28	80
Male	7	20
Curve type		
Lenke 1A Curve	26	74
Lenke 1B Curve	9	26
Flexibility		
Flexible	20	57
Rigid	15	43

Table 2: Pre-operative, fulcrum bending and post-operative Cobb angles

	Mean	Standard deviation	95% Confidence Interval
Pre-operative Cobb angle(°)	58	8	55 - 61
Fulcrum bending Cobb angle (°)	28	9	25 - 31
Post-operative Cobb angle 1 month (°)	15	6	13 – 17*
Post-operative Cobb angle 24 months (°)	16	7	14 – 18*

* Significant difference between fulcrum bending and post-operative Cobb angles ($P < 0.05$)

Table 3: Fulcrum flexibility rate, correction rates and fulcrum bending corrective index.

	Mean	Standard deviation	95% Confidence Interval
Fulcrum flexibility rate (%)	52	14	47 – 57
Correction rate 1 month (%)	74	11	70 – 78*
Correction rate 2 years (%)	72	12	68 – 76*
• Significant difference between flexibility rate and correction rates. (P < 0.05)			
FBCI 1 month (%)	152	47	137 - 168
FBCI 2 years (%)	147	48	132 - 164
Difference between FBCI at 1 month and 2 years was statistically insignificant			
FBCI flexible curves (%)	127	15	120 – 134
FBCI rigid curves (%)	187	52	158 – 215*
*Difference in FBCI between flexible and rigid curves was statistically significant			

Table 4: Pearson correlation between pre-operative Cobb angle, fulcrum bending Cobb angle, fulcrum flexibility rate with post-operative Cobb angle.

	R value	**P value**
Age	0.520	0.001
Pre-operative Cobb angle	0.171	0.326
Fulcrum bending Cobb angle	0.505	0.002
Fulcrum bending flexibility rate	-0.506	0.002

Table 5: Predicted and post-operative Cobb angles

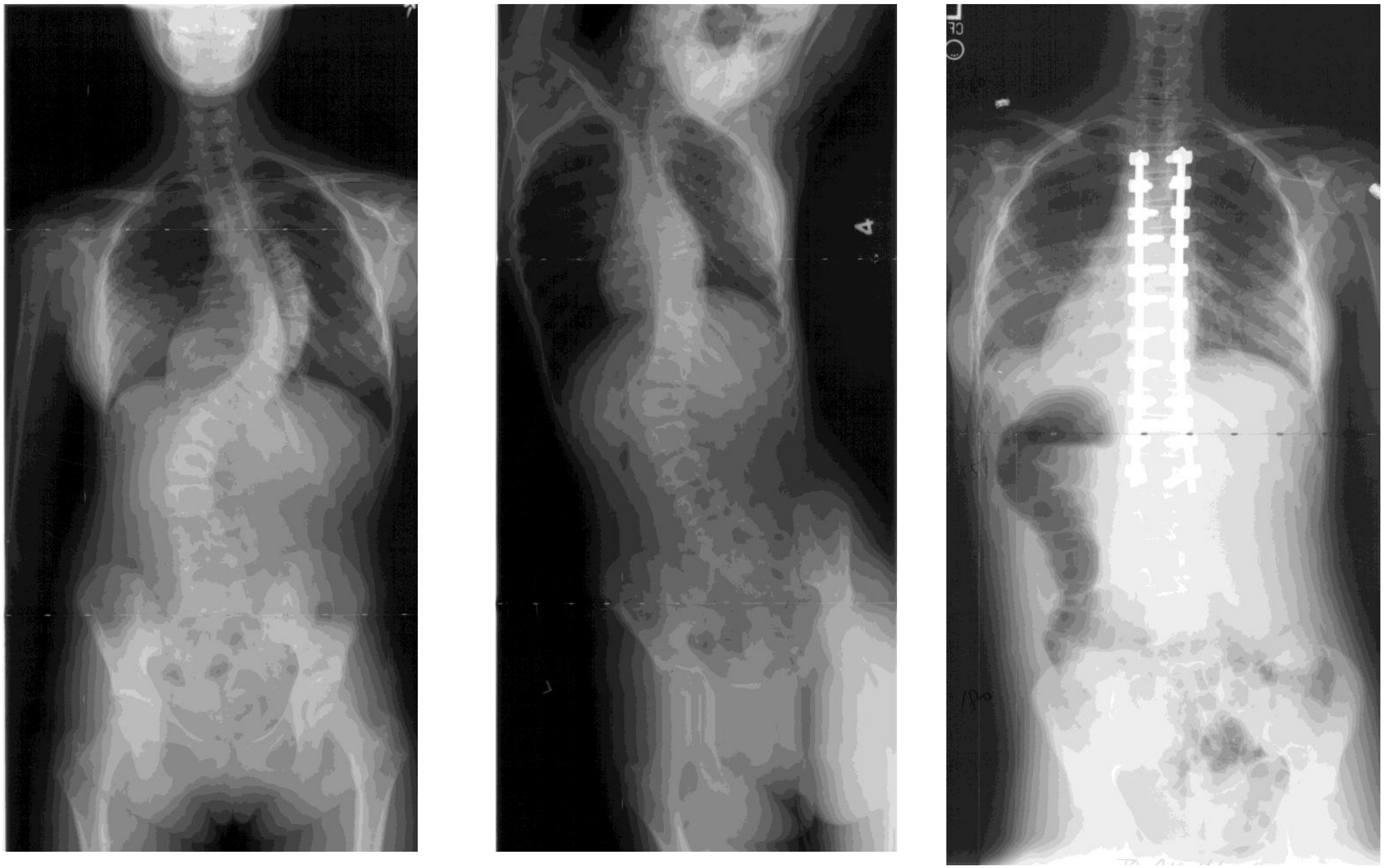
	Mean	Standard deviation (degrees)	95% Confidence Interval
Predicted Cobb angle (°)	15	4	13 - 17
Predicted minus post-operative Cobb angle 1 month (°)	0	5	-2 - 2
Predicted minus post-operative Cobb angle 2 years (°)	-1	8	-4-2

No significant difference between predicted and post-operative Cobb angles.

Figures (TIFF, EPS, or PPT only)

Figure 1:

(a) Pre-operative radiograph showed 75° Lenke 1B thoracic scoliosis
(b) Fulcrum bending unbend to 37° with fulcrum flexibility rate 51%
(c) Post-operative radiograph showed 10° with correction rate 87% and fulcrum bending corrective index 171%



a b c

Fig 2: Scatter plot with fulcrum bending corrective index against fulcrum flexibility rate.
fbci1: Fulcrum bending corrective index at 1 month
ffr: Fulcrum flexibility rate