



## Case series

## Single bundle vs double bundle for anterior cruciate ligament reconstruction evaluated with T2 mapping: A case series

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## ABSTRACT

**Introduction:** ACL reconstruction is needed to restore the stability and biomechanics properties of the injured knee joints in order to reproduce the function of the native ACL. The single-bundle (SB) and double-bundle (DB) techniques are most commonly used to reconstruct the injured ACL. However, its superiority upon each other is still controversial.

**Presentation of case:** This study presented a case series of six patients underwent ACL reconstruction, consisted of three patients with SB ACL reconstruction and three patients with DB ACL reconstruction with further T2 mapping for joint instability evaluation. Only two DB patients showed consistent decreased value in every follow-up.

**Discussion:** ACL tear can generate joint instability. Joint instability is resulted from two mechanisms of relative cartilage overloading. First, there is an abnormal load distribution due to shifting of the center of pressure of the tibiofemoral force, resulting in increased stresses on the articular cartilage of the knee joint. There is also an increase of translation between articular surfaces, resulting in increased shear stresses on the articular cartilage. A trauma of knee joint causes cartilage damage and increased oxidative and metabolic stress of chondrocytes, resulting in chondrocyte senescence acceleration.

**Conclusion:** This case series showed inconsistent results to determine either SB or DB has a better outcome in joint instability, thus further larger studies are needed.

## 1. Introduction

Anterior cruciate ligament (ACL) of the knee functions to maintain structural stability of the knee and motor function. However, ACL injury is the most common knee injuries. The incidence is estimated to be >150,000 new ACL tear every year in United States. It could lead to moderate to severe instability and mechanical imbalance, which further resulting in cartilage degeneration, meniscus injury, and early-onset osteoarthritis of the knee. Therefore, ACL reconstruction is needed in order to reproduce the function of the native ACL [1,2].

The single-bundle (SB) and double-bundle (DB) techniques are most commonly used to reconstruct the injured ACL. However, its superiority upon each other is still controversial. Several meta-analyses stated that DB techniques resulted in better knee stability and kinematics over SB techniques [3]. However, there were also randomized trials stating that single-bundle technique showed a better clinical outcome than the double-bundle techniques [4].

The clinical outcomes were mostly evaluated by using clinical examination and scorings. Evaluation using MRI T2 mapping is still uncommon. Joint instability can be evaluated using MRI T2 mapping. In the early phase of osteoarthritis, it has been shown that T2 mapping is sensitive to T2 prolongation induced by cartilage degeneration, which marked by cartilage T2 values elevation along with the severity of osteoarthritis [5]. T2 relaxation time in focal areas of cartilage will be longer if the chondral matrix got damage and loss its collagen integrity.

We presented a case series of six patients underwent ACL reconstruction, divided into two groups: single-bundle and double-bundle techniques. The T2 mapping MRI value was measured three times, before the surgery, on the 3rd month of follow-up, and 6th month of follow-up. We measured the T2 value on six points on the femoral condyle (anterior, middle, and posterior on the sagittal plane; and medial, middle, and lateral condyle on the coronal plane) in range of interest 9,8–10,0 mm<sup>2</sup> areas. The values were then averaged. This case report has been reported in line with the PROCESS Guideline [6].

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## 2. Case presentation

We presented a case series of six patients underwent ACL reconstruction, consisted of three patients with SB ACL reconstruction and three patients with DB ACL reconstruction (Table 1). All the patients were physically active and served in military service. All the primary reconstruction was done under one-year gap after the injury. We evaluated the compartments of the knee using MRI T2 mapping in sagittal and coronal view. We measured the T2 values before the surgery and during the follow-up, three and six months after the surgery (Table 2). MRI T2-mapping images in SB and DB ACL reconstruction patients was shown in Figs. 1 and 2.

Patients in the SB group showed a consistent pattern of T2 value changes, where the values in the 3rd month tend to increase, followed with a decrease in the following 3 months. On the other hand, two patients from the DB group (DB1 and DB2) showed a consistent decrease of T2 value after operation. Interestingly, patient DB3 showed the similar trend observed in the SB group.

It was concluded that only two patients in DB group showing a promising result of ACL reconstruction with consistent decreased value in every follow-up, while the others are needed to be further evaluated.

## 3. Discussion

ACL tear can generate joint instability. Joint instability is resulted from two mechanisms of relative cartilage overloading. First, there is an abnormal load distribution due to shifting of the center of pressure of the tibiofemoral force, resulting in increased stresses on the articular cartilage of the knee joint. There is also an increase of translation between articular surfaces, resulting in increased shear stresses on the articular cartilage. A trauma of knee joint causes cartilage damage and increased oxidative and metabolic stress of chondrocytes, resulting in chondrocyte senescence acceleration [7].

As the MRI T2 mapping value is supposed to be decreasing over the period of time, the results of this case series did not show the expected pattern. Only two patients underwent DB ACL reconstruction reported for having a consistent decreased value in every follow-up MRI examination. None of the other patients showed this pattern, moreover, it showed an increased value on the 3rd month of follow-up.

There were already many conducted meta-analyses comparing SB and DB ACL reconstruction. Chen et al. included studies of ACL reconstruction with the minimum of 3-year follow-up with the result of double-bundle ACL reconstruction improved knee rotational stability effectively with higher subjective functional scores compared to single-bundle techniques at the mid-term follow-up [8]. Several meta-analyses also produced similar results, that DB ACL reconstruction was superior in terms of knee kinematics restoration, especially anterior-posterior laxity [9], significantly lower the incidence of graft failure [4], improved also objective function and knee stability used as revision procedure regardless the primary techniques of reconstruction [9,10]. However, Dong et al. failed to show the superiority of double-bundle with the result there was no statistically significant difference in

**Table 2**

T2 mapping value evaluated on pre-reconstruction, 3rd month, and 6th month follow-up.

	Pre-reconstruction	3rd month	6th month
Single Bundle 1	78,61	89,73	56,28
Single Bundle 2	61,11	66,57	43,84
Single Bundle 3	48,43	63,43	51,33
Double Bundle 1	84,72	81,96	80,78
Double Bundle 2	81,94	74,28	70,06
Double Bundle 3	45,75	47,13	44,39

double-bundle and single-bundle ACL reconstruction [3].

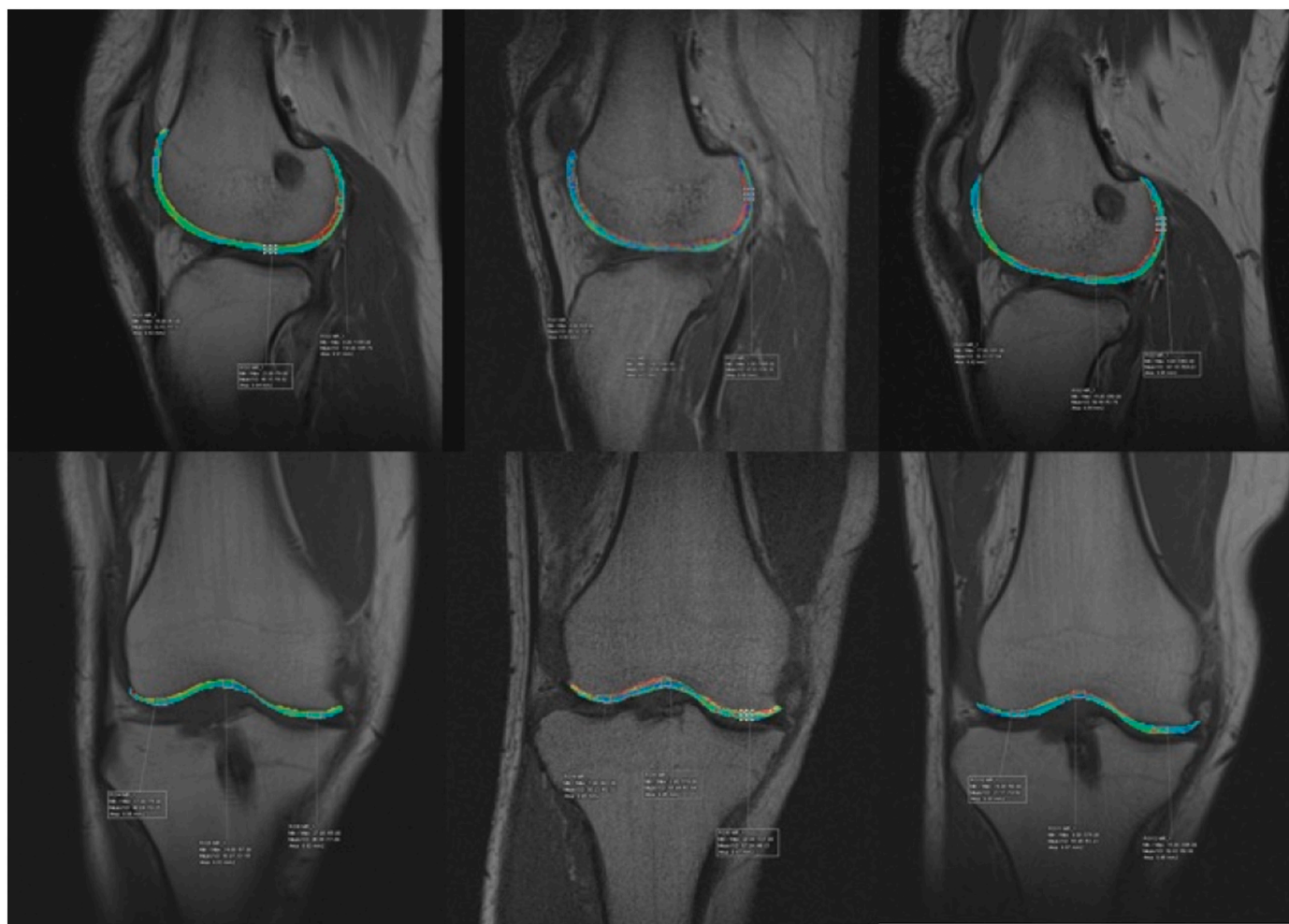
Ahn et al. searched the possible risk factor for knee instability after ACL reconstruction and found that concomitant grade 2 medial cruciate ligament (MCL) injury and delayed reconstruction over 12 weeks from injury significantly predisposed joint instability postoperative ACL reconstruction. It also stated that reconstruction techniques, using either SB or DB, did not significantly cause joint instability after ACL reconstruction [11]. However, in this presented case series, patient SB 1 and 2 were both underwent the operation 3–6 months after the injury, while the others <3 month with nobody had any concomitant grade 2 MCL injury.

Senorski et al. conducted a systematic review about factors affecting patient reported outcome after ACL reconstruction and found that younger age, male sex, non-smoker, and the absence of concomitant injuries were associated with superior outcomes after ACL reconstruction. Similar to Ahn et al., the study showed no significant difference of outcome between SB and DB group. However, patients underwent DB ACL reconstruction reported superior Knee injury and Osteoarthritis Outcome Score (KOOS) quality of life at 5th year follow-up [12,13]. All the patients included in this case series were all male, however, we could not further analyze as we did not include female patients. Patient SB 1 and 2 are the youngest amongst all, with the age of 23 years old. Patient SB 3 and DB 2 shared the same age of 36 years old. Therefore, this could be one factor affecting the promising result of ACL reconstruction in patient SB 1 and 2. All of the patients has concomitant injuries, most commonly lateral meniscus tear.

Evaluation of joint instability after ACL reconstruction with T2 mapping was suggested. Kijowski et al. reported that adding T2 mapping on the evaluation protocol improved sensitivity in detecting cartilage lesion up to 88 % with moderate specificity [13]. Niki et al. also stated that T2 mapping was feasible to evaluate graft maturation after anatomic DB ACL reconstruction as it successfully detected purely tendinous portions of the graft [14]. However, T2 mapping also has several limitations. A “magic angle effect” is a term when the technique of magic angle spinning was used to reduce the residual dipolar interaction of crystalline solids in nuclear MR spectroscopy. T2 relaxation is prone to this magic angle effects, when collagen fibers are oriented 55° relative to the applied magnetic field ( $B_0$ ), resulting in minimalization of relaxation mechanism and longer T2. Artifact from the magic angle effect can cause diagnostic error because elevated T2 value is associated with cartilage damage. In addition, T2 measurements are also not very

**Table 1**  
Patients' characteristics.

Patient	Age	Weight (kg)	BMI (kg/m <sup>2</sup> )	Time of reconstruction	Diagnosis	Intraoperative
SB 1	21	70	24,80	3–6 month	ACL + lateral + medial meniscus (right)	SB ACL reconstruction, medial + lateral meniscectomy
SB 2	21	70	22,86	3–6 month	ACL + lateral meniscus (left)	Meniscus tear lateral → partial meniscectomy, SB ACL reconstruction, cartilage intact
SB 3	34	63	22,06	1–3 month	ACL tear + meniscus tear middle & lateral (right)	SB ACL reconstruction, lateral meniscus repair, meniscus medial normal
DB 1	29	71	23,18	<1 month	ACL + lateral meniscus (left)	DB ACL reconstruction, meniscus or cartilage intact
DB2	35	68	24,15	6–9 month	ACL + lateral meniscus tear (right)	DB ACL reconstruction + meniscus lateral partial tear
DB 3	22	63	21,80	<1 month	ACL + lateral meniscus (left)	DB ACL reconstruction + stable tear medial meniscus



**Fig. 1.** MRI T2 mapping sagittal (up) and coronal (down) view from the pre-reconstruction (left), 3rd month follow-up (middle), and 6th month follow-up (right) of patient SB 1, showing consistent decreased value over time.

reliable for the calcified and deep layer of cartilage, in which the spin-spin relaxation time is shorten [15].

This study has several limitations. In this study, the MRI T2 mapping evaluation was conducted only by one examiner, thus there might be a bias on the value, as there were inconsistent value changes between the views. The sample is too small to be analyzed, therefore, further larger and multi-centered studies evaluating the difference of SB and DB techniques in the term of joint instability using MR T2 mapping after ACL reconstruction is needed.

#### 4. Conclusion

This case series showed inconsistent results to determine either SB or DB has a better outcome in joint instability, thus further larger studies are needed. MRI T2 mapping might be a promising diagnostic tool to evaluate the difference between SB and DB techniques in term of joint instability.

#### Consent

Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

#### Ethical approval

We do not have ethical approval from our institution since all patients' identity were blinded in this case series and did not intervene with patients' treatment plans.

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NA.

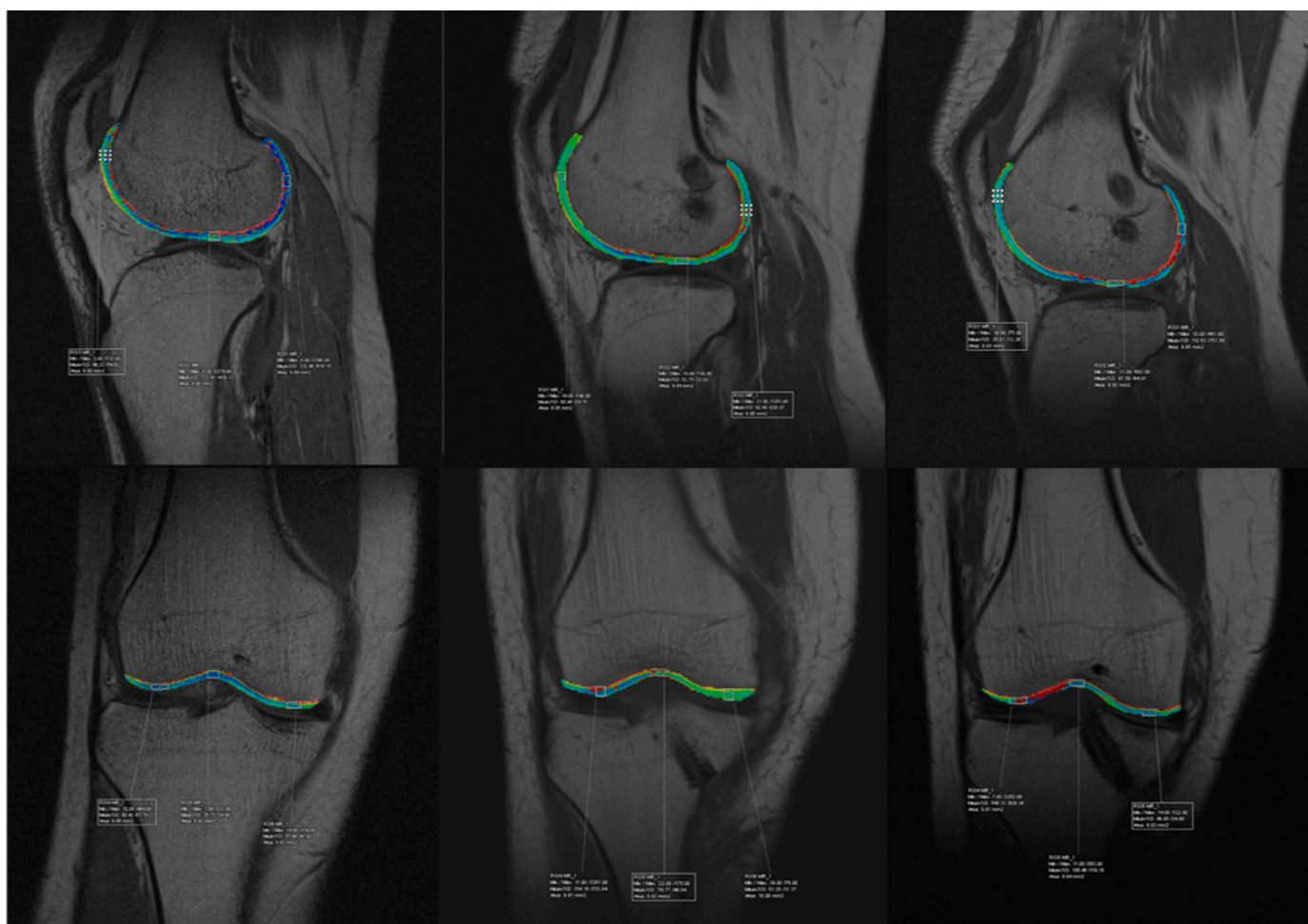
#### Author contribution

Bobby N Nelwan: study concept or design, data collection, analysis and interpretation, oversight and leadership responsibility for the research activity planning and execution.

Andri MT Lubis: study concept or design, data collection, analysis and interpretation, oversight and leadership responsibility for the research activity planning and execution.

Ismail H Dologo: study concept or design, data collection, analysis and interpretation, oversight and leadership responsibility for the research activity planning and execution.

Alberto L Hanitya: study concept or design, data collection, analysis and interpretation, oversight and leadership responsibility for the research activity planning and execution



**Fig. 2.** MRI T2 mapping sagittal (up) and coronal (down) view from the pre-reconstruction (left), 3rd month follow-up (middle), and 6th month follow-up (right) of patient DB

## Guarantor

Andri Maruli Tua Lubis, MD.

## Research registration number

Not applicable.

## Declaration of competing interest

NA.

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## References

- [1] S.L.Y. Woo, C. Wu, O. Dede, F. Vercillo, S. Noorani, Biomechanics and anterior cruciate ligament reconstruction, *J. Orthop. Surg. Res.* 1 (2) (2006 Sep 25) 1–9.
- [2] C. He, W. He, Y. Li, F. Wang, L. Tong, Z. Zhang, et al., Biomechanics of knee joints after anterior cruciate ligament reconstruction, *J. Knee Surg.* 31 (04) (2018) 352–358.
- [3] Z. Dong, Y. Niu, J. Qi, Y. Song, F. Wang, Long term results after double and single bundle ACL reconstruction: is there any difference? A meta - analysis of randomized controlled trials, *Acta Orthop. Traumatol. Turc.* 53 (2019) 92–99.
- [4] S. Järvelä, T. Kiekara, P. Suomalainen, T. Järvelä, Double-bundle versus single-bundle anterior cruciate ligament reconstruction, *AJSM* 45 (11) (2017) 2578–2585.
- [5] R. Dautry, V. Bousson, J. Manelfe, A. Perozziello, P. Boyer, P. Loriaut, et al., Correlation of MRI T2 mapping sequence with knee pain location in young patients with normal standard MRI, *JBR-BTR* 97 (2014) 11–16.
- [6] R. Agha, C. Sohrabi, G. Mathew, T. Franchi, A. Kerwan, N. O'Neill, et al., The PROCESS 2020 guideline: updating consensus Preferred Reporting Of CasE Series in Surgery (PROCESS) guidelines, *Int. J. Surg.* 84 (2020) 231–235.
- [7] A. Heijink, A.H. Gomoll, H. Madry, M. Drobnic, G. Filardo, J. Espregueira-Mendes, et al., Biomechanical considerations in the pathogenesis of osteoarthritis of the knee, *Knee Surg. Sports Traumatol. Arthrosc.* 20 (2012) 423–435.
- [8] G. Chen, S. Wang, Comparison of single-bundle versus double-bundle anterior cruciate ligament reconstruction after a minimum of 3-year follow-up: a meta-analysis of randomized controlled trials, *Int. J. Clin. Exp. Med.* 8 (9) (2015) 14604–14614.
- [9] C. Jiang, G. Chen, P. Chen, W. Li, H. Zhang, W. Zhang, Double-bundle revision anterior cruciate ligament reconstruction is effective in rescuing failed primary reconstruction and re-introducing patients to physical exercise, *Exp. Ther. Med.* 15 (2018) 2074–2080.
- [10] P. Aglietti, F. Giron, P. Cuomo, M. Losco, N. Mondanelli, Single- and double-incision double-bundle ACL reconstruction, *Clin. Orthop. Relat. Res.* 454 (2007) 108–113.
- [11] J.H. Anh, S.H. Lee, Risk factors for knee instability after anterior cruciate ligament reconstruction, *Knee Surg. Sports Traumatol. Arthrosc.* (2015) 2936–2942.
- [12] E.H. Senorski, E. Svantesson, A. Baldari, O.R. Ayeni, L. Engebretsen, F. Franceschi, et al., Factors that affect patient reported outcome after anterior cruciate ligament reconstruction—a systematic review of the scandinavian knee ligament registers, *Br. J. Sports Med.* (2018) 1–9.
- [13] R. Kijowski, D. Blankenbaker, A. de Smet, G. Baer, B. Graf, T2 mapping sequence for detecting cartilage lesion within the knee joint at 3.0T: diagnostic performance

- in 114 patients with surgical correlation, *Proc. Intl. Soc. Mag. Reson. Med.* (2012) 20.
- [14] Y. Niki, T. Yasuoka, S. Kobayasi, K. Harato, T. Nagura, S. Okuda, et al., Feasibility of T1rho and T2 map magnetic resonance imaging for evaluating graft maturation after anatomic double-bundle anterior cruciate ligament reconstruction, *J. Orthop. Surg. Res.* 14 (140) (2019) 1–8.
- [15] A. Guermazi, H. Alizai, M. Crema, S. Trattnig, R. Regatte, F.W. Roemer, Compositional MRI techniques for evaluation of cartilage degeneration in osteoarthritis, *Osteoarthr. Cartil.* 23 (2015) 1639–1653.