Title 論文題目	成長期の児童における単椎体，多椎体腰椎分離症の保存治療成績 1. Conservative treatment of lumbar spondylolysis in young athletes. Early athletic rehabilitation focusing on core training did not exert an effect on bone healing especially in early stage, which the defects were still incomplete separation. （若年アスリートにおける腰椎分離症の保存療法．初期（不完全分離）は体幹トレーニングを中心としたアスレチックリハビリテーションを早期に開始しても骨癒合率は低下しない） 2. Prevalence of multiple-level spondylolysis and the bone union rates among growth-stage children with lower back pain （腰痛を訴える成長期の児童における多椎体分離症の頻度と骨癒合率）
Author(s) 著者	家里，典幸
Degree number 学位記番号	乙第3175号
Degree name 学位の種別	博士(医学)
Issue Date 学位取得年月日	2022-03-30
Original Article 原著論文	1:Jpn J Sports Med 2022; 42 2:Spine Surg Relat Res. 2021 Feb 22;5(4):292-297
Doc URL	
DOI	1:10.34473/jossm.42.1_48 2:10.22603/ssrr.2020-0165
Resource Version	Publisher Version

Conservative Treatment of Lumbar Spondylolysis in Young Athletes Early Athletic Rehabilitation Focusing on Core Training did not Exert an Effect on Bone Healing Especially in Early Stage, which the Defects were Still Incomplete Separation

若年アスリートにおける腰椎分離症の保存療法 初期（不完全分離）は，体幹トレーニングを中心としたアスレチックリハビリテーションを早期に開始しても骨癒合率は低下しない

家里　典幸[1)]　Noriyuki Iesato
寺本　篤史[1)]　Atsushi Teramoto
射場　浩介[1)]　Kousuke Iba
神谷　智昭[1)]　Tomoaki Kamiya
渡邉　耕太[2)]　Kota Watanabe
山下　敏彦[1)]　Toshihiko Yamashita

● Key words
腰椎分離症，アスレチックリハビリテーション，骨癒合率
Spondylolysis; Athletic rehabilitation; Bony healing rate

● Abstract

Purpose: We thought that early athletic rehabilitation focusing on core training does not exert an effect on bone healing for lumbar spondylolysis. This study aimed to investigate the bony healing rate and the period for our conservative treatment.

Subjects and Methods: We examined young athletes（age≤18 years), who visited one institution between April 2013 and March 2016, with the chief complaint of lumbar pain, and who were diagnosed with lumbar spondylolysis.

Results: A total of 97 young athletes with lumbar spondylolysis that included 132 pars interarticularis were enrolled. The bony healing rate and the healing period was 93.1% and 3.3 months in early stage, and 56.7% and 5.4 months in progressive stage, respectively.

Conclusions: Especially in the early stage which the defects were still incomplete separation, early athletic rehabilitation focusing on core training did not exert an effect on bone healing.

家里典幸
〒060-8543　札幌市中央区南1条西16丁目
札幌医科大学医学部整形外科学講座
TEL 011-611-2111
E-mail niesato@sapmed.ac.jp
Noriyuki Iesato
S1 W16, Sapporo, Hokkaido 060-8543, Japan
Department of Orthopaedic Surgery, Sapporo Medical University School of Medicine
TEL ＋81-11-611-2111/FAX ＋81-11-641-6026

1）札幌医科大学医学部整形外科学講座
Department of Orthopaedic Surgery, Sapporo Medical University School of Medicine
2）札幌医科大学保健医療学部理学療法学第二講座
Department of Physical Therapy, Sapporo Medical University School of Health Sciences

Introduction

Lumbar spondylolysis results from a stress fracture that occurs as a result of repeated load placement on the lumbar pars interarticularis owing to sporting or similar activities during the growth phase[1-3]. If lumbar spondylolysis is diagnosed early and is in the early or progressive stage, patients can attain bony healing for conservative treatment[4-8]. However, to attain bony healing, sporting activities should be discontinued for 3-6 months, which poses a challenge for athletes that could result in decreased performance and loss of a regular position. Thus, the young athletes typically want to restart exercising as soon as possible, and to demonstrate sufficient performance right after the return to the sports, and to prevent any recurrence. However, the extent to which exercise can be allowed, and how quickly the patient can return to sports without exerting a harmful impact on bony healing remain unclear. This study aimed to investigate the bony healing rate and the healing period for conservative treatment of lumbar spondylolysis and the impact of athletic rehabilitation on bony healing.

Materials and Methods

In this study, we examined young athlete (elementary school children to adolescents, age≤18 years), who visited the Sports Medical Center in Obihiro Kyokai Hospital (Obihiro city, Hokkaido, Japan), between April 2013 and March 2016, with the chief complaint of low back pain, and who were diagnosed with lumbar spondylolysis. The study cohort only comprised patients with single-level spondylolysis. We excluded patients with multi-level spondylolysis which affected two or more vertebral arches.

To diagnose lumbar spondylolysis, all patients with the chief complaint of lumbar pain lasting more than 2 weeks, and severe back pain that made it difficult to continue sports at the initial examination underwent lumbar radiographic imaging (standing position, four directions: frontal, lateral, anteflexion, and retroflexion) and lumbar computed tomography (CT) (Toshiba, Aquillion, slice thickness 2 mm). For lumbar CT, we recreated sagittal and oblique axial images along the vertebral arches and evaluated the presence or absence of the pars defect. To ensure that we did not miss the defect, we paid attention to the defect occurring from the ventral side of the lamina[7]. We performed additional lumbar magnetic resonance imaging (MRI) (Toshiba, Vantage Titan 3T) on patients in whom the pars defect was revealed on a lumbar radiograph or CT, and even if the pars defect was absent on lumbar CT imaging, we performed lumbar MR imaging on patients with spinous process tenderness or lumbar extension pain. We evaluated the presence or absence of bone marrow edema at the pedicle presenting as hypointense signals on T1-weigheted images, and hyperintense signals on T2-weigheted images, and T2 fat-suppressed images. Bone marrow edema at the pedicle can be regarded as a stress reaction on the lamina; therefore, its presence indicates early onset spondylolysis[8]. We used these images to diagnose and classify the stage of lumbar spondylolysis based on a modification of the categorizations used by Fujii and Sairyo[5, 6, 9]. We performed staging of each pars defect as follows: Among the pars defects exhibiting bone marrow edema in the adjacent vertebral pedicle, the defect limited to the ventral side of the vertebral arch and bony continuity on the dorsal side (incomplete separation) in CT sagittal images were considered in the early stage, and the defect extended to the dorsal side of the vertebral arch (complete separation) were considered in the progressive stage. Among the pars defects without bone marrow edema in the pedicle, the defects were confirmed that the separation has reached the dorsal side of the vertebral arch (complete separation) and checked whether the edge of the separation has sclerosed or rounded in CT sagittal images. In CT images, not sclerosed or sharp margin of the edges were considered in the progressive stage and sclerosed or rounded margin of the edge were considered in the terminal stages (Figure 1).

We implemented athletic rehabilitation directly after diagnosis to facilitate early return to sports, prevent decreased performance after returning to sports, and prevent any recurrence. Specifically, our method comprised the following steps: (1) temporarily discontinuing participation in sports and implementation of athletic rehabilitation focusing on core training; (2) using a soft night orthosis for sports as a soft trunk corset (night orthosis for sports: MAXBELT S3 [Nippon Sigmax Co., Ltd., Tokyo, Japan] ; (3) engaging in light exercise, such as jogging, when the spinous process tenderness in the abdominal position and lumbar extension pain disappeared; and (4) allowing patients to return to sports upon confirming bone formation on CT, even if complete bony healing was not observed (Figure 2). The orthosis was removed once patients could

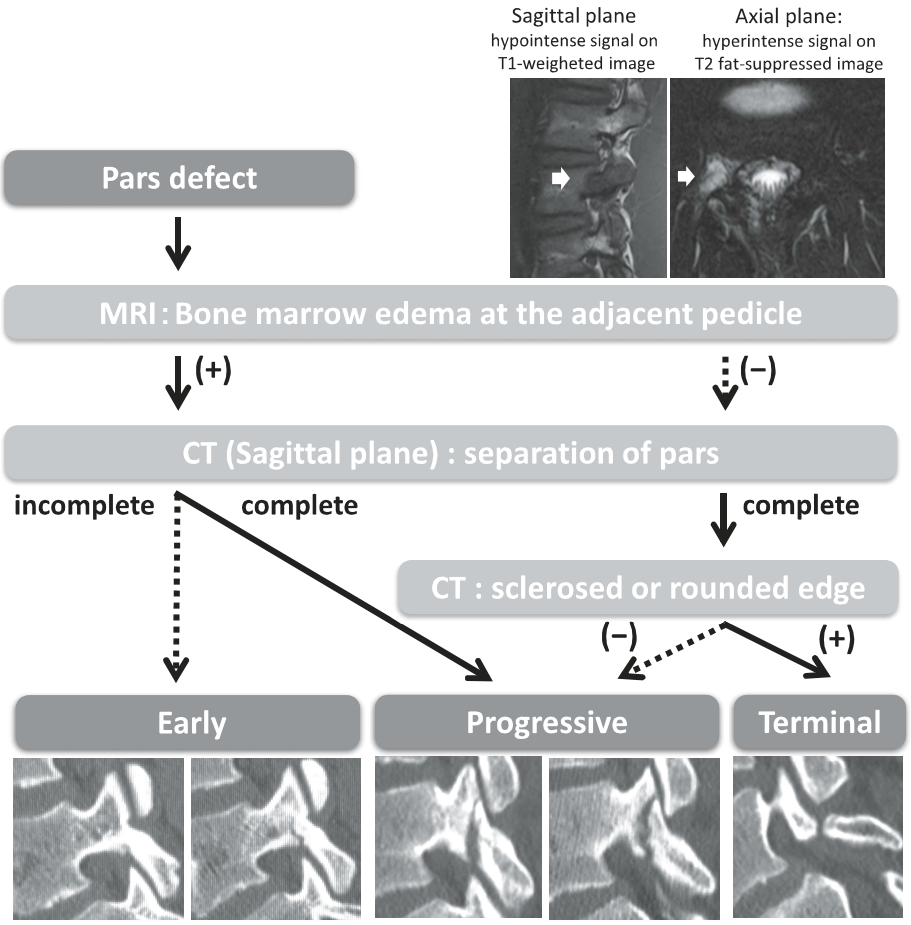

Figure 1　X-P, CT and MRI stage classification for spondylolysis

Figure 2　Bony healing process for the pars of spondylolysis on CT sagittal imaging. (A) The pars defect extended to the dorsal side of the vertebral arch (complete separation) and the edge is not sclerosed, so considered in progressive stage. (B) Bone formation is confirmed at the pars defect. It occurs from the dorsal side to ventral side of the vertebral arch, which in the opposite direction of the developing separation. (C) Bony healing is confirmed at the pars defect.

engage in sports at the maximum intensity with no low back pain.

The order of athletic rehabilitation was as follows: (1) increasing thoracic and hip mobility by stretching; (2) activating deep trunk muscles with abdominal draw-in; (3) implementing core stabilization exercises, such as abdominal curls, bird-dogs, side-bridges, and back-bridges, to stabilize the spinal column, and promote segment movement of the spine with the cat-camel exercise[10-14].

We used lumbar CT to evaluate bony healing and performed imaging on only the affected vertebrae once every 1-2 months, with by follow-up monitoring until bony healing was achieved or pseudarthrosis was exhibited. Because bony healing of the most ventral side of the vertebral arch is typically delayed, we considered bony healing to have occurred if at least 75% of the vertebral arch had attained bony healing.

Table 1 Characteristics of 97 Patients, 132 vertebral arches

		Number (Patient)	Percentage
· School	Elementary	14	14.4%
	Junior high	55	56.7%
	High	28	28.9%
· Sex	Male	72	74.2%
	Female	25	25.8%
· Separation site	Unilateral	49	50.5%
	Bilateral	48	49.5%
· Separation site level	L2	2	2.1%
	L3	4	4.1%
	L4	26	26.8%
	L5	65	67.0%
		Number (Vertebral arches)	
· Stage classification	Early	102	77.3%
	Progressive	30	22.7%

We implemented treatment that aimed for bony healing in the early and progressive stage, and pain management in the terminal stage. Regarding the patients in the terminal stage, athletic rehabilitation was implemented, and a return to sports was allowed once the patient's pain disappeared. We investigated the outcomes of conservative treatment (the bony healing rate and bony healing period) in patients with lumbar spondylolysis in the early and progressive stage with regards to school year, sex, separation site (unilateral or bilateral), separation site level (L2 and L3, L4, or L5), and stage classification (early, progressive).

Statistical Analysis was performed with IBM SPSS Statistics ver. 24.0 (IBM Corp., Armonk, NY, USA). The Fisher's exact test and Student's t-test were used for comparison between the two groups, and one-way ANOVA and Tukey-Kramer method were used for comparison between the three groups, and p values of <0.05 were considered statistically significant.

This study was approved by the Ethics Committee of the Obihiro Kyokai Hospital (Obihiro city, Hokkaido, Japan). The approval number is "Obi-Kyokai 2015-16".

Results

In this study, 107 patients who were younger than 18 years (72 males and 25 females) were diagnosed with single-level lumbar spondylolysis, which were in the early or progressive stage. Of these, we implemented athletic rehabilitation with follow-up monitoring in 97 patients (mean age 14.2±2 years), including 132 vertebral arches. The follow-up rate was 90.7%, and the mean follow-up period was 189.3± 93.2 days. Regarding separation sites, 49 patients showed unilateral and 48 showed bilateral. For separation site level, 2 patients showed L2, 4 showed L3, 26 showed L4, and 65 showed L5. A total of 102 vertebral arches were classified as early, and 30 were classified as progressive (Table 1).

The bony healing rate was 62.5% in elementary school students, 89.7% in junior high school students, and 85.4% in high school students. The bony healing rate was significantly lower in elementary school students compared to junior high school students ($P<0.05$). The bony healing rate was 84.0% in males and 87.5% in females, exhibiting no significant difference between the sexes. The bony healing rate was 93.9% for unilateral separation and 79.5% for bilateral separation. The bony healing rate was significantly higher in unilateral compared to bilateral separation ($P<0.05$). Regarding the separation site level, the bony healing rate was 85.7% in L2 and L3, 92.5% in L4, and 81.2% in L5, demonstrating no significant difference between the groups. The bony healing rate was 93.1% in the early stage, and 56.7% in the progressive stage. Thus, the bony healing rate was significantly higher in the early compared to the progressive stage ($P<0.01$; Table 2).

Overall, the bony healing period was 112.7±53.7 days in this study. The bony healing period was 145.0 ±51.4 days in elementary school students, 113.7±62.8 days in junior high school students, and 100.6±32.5 days in high school students. Thus, the period until the occurrence of bony healing was significantly longer in elementary school students than in high school students ($P<0.05$). The bony healing period was 115.6± 56.9 days for males and 103.6±41.5 days for females, revealing no significant difference. The bony healing

Table 2 The outcomes of conservative treatment (the bony healing rate and period)

		Bony union rate	Numbar (union/Total)	Bony healing period (mean ± SD)
・School	Elementary	62.5%	(10/16) *	145.0 ± 51.4 *
	Junior high	89.7%	(61/68)	113.7 ± 62.8
	High	85.4%	(41/48)	100.6 ± 32.5
・Sex	Male	84.0%	(84/100)	115.6 ± 56.9
	Female	87.5%	(28/32)	103.6 ± 41.5
・Separation site	Unilateral	93.9%	(46/49) *	107.0 ± 47.4
	Bilateral	79.5%	(66/83)	116.1 ± 58.0
・Separation site level	L2.3	85.7%	(6/7)	101.1 ± 39.6
	L4	92.5%	(37/40)	99.4 ± 36.2
	L5	81.2%	(69/85)	119.9 ± 60.2
・Stage classification	Early	93.1%	(95/102) **	98.6 ± 34.2 **
	Progressive	56.7%	(17/30)	160.7 ± 76.5
・Total		84.8%	(112/132)	112.7 ± 53.7

SD, standard deviation, *$p<0.05$, **$p<0.01$.

period was 107.0 ± 47.4 days in unilateral separation and 116.1 ± 58.0 in bilateral separation, indicating no significant difference. The bony healing period according to separation site level was 101.1 ± 39.6 days for L2 and L3, 99.4 ± 36.2 days for L4, and 119.9 ± 60.2 days for L5 revealing no significant difference. The bony healing period by stage classification was 98.6 ± 34.2 days (3.3 months) in the early stage, and 160.7 ± 76.5 days (5.4 months) in the progressive stage. Thus, the bony healing period was significantly shorter in early stage compared to progressive stage ($P<0.01$; Table 2).

Discussion

Bony healing can be attained in patients with lumbar spondylolysis by discontinuing sports and implementing fixation with a trunk corset if detected early after onset. However, concerns have been raised as to whether early athletic rehabilitation decreases the bony healing rate or prolongs the bone healing period; therefore, we investigated the treatment results in this study. In the early and the progressive stage, the bony healing rate in this study was 93.1% and 56.7%, and the bone healing period was 3.3 and 5.4 months, respectively. Sairyo et al. reported a healing rate of 82%-94% and a healing period of 3.2 months in early stage, and a healing rate of 60%-64% and healing period of 5.4 months in the progressive stage[6, 8], which are consistent with the results of our study and no prolonged bone union period was observed with early athletic rehabilitation. Especially in the early stage, which the defects were still incomplete separation, the bony healing rate was more than 90% and the healing period was within 3.5 months, which suggests that early athletic rehabilitation focusing on core training does not exert an effect on bone healing.

The extent to which exercise can be allowed without adversely affecting the bony healing rate during the discontinuation period of sports remains unclear. Treatment at our hospital is characterized by initiating athletic rehabilitation that focuses on core training after diagnosis. Panjabi defined the range of motion in which appropriate load was applied to joint components such as bones, capsules, and ligaments as the neutral zone, and the range of motion in which excessive load was applied to joint components as the elastic zone[15]. Facet joints movement beyond the elastic zone will be considered to promote separation of the pars, and it is important to exercise within the neutral zone in order to achieve bony healing. It is considered that the core training is within the neutral zone without excessive bending or twisting of the spine, so we considered no exert an effect on bony healing. In addition, since lumbar spondylolysis comprises stress fractures, aiming for bony healing and preventing recurrence warrants improvement that considers the burden being placed on the separation site. Reportedly, specific training for muscles around the spinal column (deep abdominal muscles and lumbar multifidus) was effective to reduce chronic lumbar pain in adult patients with lumbar

spondylolysis, because stabilization of the spinal column reduced the burden on the separation site[14]. Thus, we thought that reducing the burden on the separation site with specific training of the muscles around the spinal column could also be effective in young patients with early phase spondylolysis, which is why we incorporated it into the athletic rehabilitation for our study population. Considering that our outcomes for the bony healing rate and bony healing period aligned with those of previous studies, it suggests that athletic rehabilitation that focuses on core training does not exert an effect on bony healing.

There is no consensus regarding the initiation time for re-engagement in sports. Patients with lower limb stress fractures are recommended to gradually increase activity after several weeks of rest and following the improvement of symptoms[16, 17]. We speculated that the same might be true for patients with spondylolysis; therefore, we allowed light exercise, such as jogging, once the spinous process tenderness in the abdominal position and lumbar extension pain disappeared. In the typical healing process for stress fractures, bone formation occurs after bone resorption, resulting in bone remodeling[18]. We considered it unlikely that pseudoarthrosis would develop if healing progressed from the bone resorption period to the bone formation period. We therefore allowed our patients to return to sports once bone formation was confirmed on CT images. Consequently, we observed no progression to pseudoarthrosis in any of the patients that exhibited bone formation.

The trunk corset that we used in this study was a soft night orthosis for sports. Hard corsets are recommended because Sairyo et al. reported that the bony healing rate increased by changing from a soft to a hard corset. They found that the hard corset inhibited extension and rotation of the lumbar vertebrae more than the soft corset[6]. In our opinion, to stabilize the trunk, it is more essential to provide the power of internal fixation that is accompanied by the increased abdominal pressure over the power of external fixation that is provided with a corset. We consider the first stage of treatment is that to attain spinal stability by increase the abdominal pressure with draw-in and activate of deep trunk muscles. Hence, we used a soft corset to obtain support by increasing the abdominal pressure. Another advantage of a soft corset is that it can be fitted during athletic rehabilitation and when restarting sports. However, in this study, the bony healing rates by each parameter was lower the patients in elementary school, with bilateral separations, and in the progressive stage. It has been reported that it is difficult to obtain bony healing in bilateral separations and in the progressive stage[5]. Early diagnosis is important because complete separation makes bone union difficult. Elementary school children do not have sufficient core trunk muscle strength, and often find it difficult to maintain in the neutral zone of the spine during exercises. For elementary school children who do not have sufficient core trunk muscle strength, care should be taken as the core training may promote separation of the pars. Thus, stable fixation with a hard corset could be an option for these patients.

This study has some limitations. First, we included no control group. Between April 2009 and March 2013, we stopped exercising after the diagnosis, and resumed from light exercise after the back pain disappeared. Among 49 young athletes with lumbar spondylolysis that included 52 pars interarticularis, the bony healing rate was 90.7% in early stage, and 44.4% in progressive stage. Although it was not possible to make a simple comparison due to different some backgrounds, the bony healing rate in this study did not show a clear decrease compared to the result before introduction of early athletic rehabilitation. So, it would appear that athletic rehabilitation that focuses on core training does not exert an effect on bony healing. Second, we did not investigate recurrence rates. The average follow-up period was 189.3 days (6.3 months), but there may be cases of recurrence after that. Through athletic rehabilitation, we identify the factors that cause repeated load on the lumbar spine, modify the usage of the body during exercise, and reduce the mechanical load on the lumbar spine. We also expect that the recurrence rate will decrease, but further follow-up and investigation are required in the future.

Conclusion

In conclusion, the bony healing rate in our patients with lumbar spondylolysis was 93.1% in early stage, and 56.7% in progressive stage, and the bony healing period was 98.6 and 160.7 days, respectively. These results corroborate with previous studies and imply that early athletic rehabilitation focusing on core training did not exert an effect on bone healing especially in early stage which the defects were still incomplete separation.

References

1) Wiltse LL et al: Fatigue fracture: the basic lesion is inthmic spondylolisthesis. J Bone Joint Surg Am, 57: 17-22, 1975.
2) Farfan HF et al: The mechanical etiology of spondylolysis and spondylolisthesis. Clin Orthop Relat Res, 117: 40-55, 1976.
3) Fredrickson BE et al: The natural history of spondylolysis and spondylolisthesis. J Bone Joint Surg Am, 66: 699-707, 1984.
4) Klein G et al: Nonoperative treatment of spondylolysis and grade I spondylolisthesis in children and young adults: a meta-analysis of observational studies. J Pediatr Orthop, 29: 146-156, 2009.
5) Fujii K et al: Union of defects in the pars interarticularis of the lumbar spine in children and adolescents. The radiological outcome after conservative treatment. J Bone Joint Surg Br, 86: 225-231, 2004.
6) Sairyo K et al: Conservative treatment for pediatric lumbar spondylolysis to achieve bone healing using a hard brace: what type and how long?: Clinical article. J Neurosurg Spine, 16: 610-614, 2012.
7) Terai T et al: Spondylolysis originates in the ventral aspect of the pars interarticularis: a clinical and biomechanical study. J Bone Joint Surg Br, 92: 1123-1127, 2010.
8) Sairyo K et al: MRI signal changes of the pedicle as an indicator for early diagnosis of spondylolysis in children and adolescents: a clinical and biomechanical study. Spine, 31: 206-211, 2006.
9) Iesato N et al: Prevalence of multiple-level spondylolysis and the bone union rates among growth-stage children with lower back pain. Spine Surg Relat Res, 5: 292-297, 2021.
10) Hodges PW et al: Contraction of the abdominal muscles associated with movement of the lower limb. Phys Ther, 77: 132-144, 1997.
11) Kavcic N et al: Determining the stabilizing role of individual torso muscles during rehabilitation exercises. Spine, 29: 1254-1265, 2004.
12) McGill SM: Low back stability: from formal description to issues for performance and rehabilitation. Exerc Sport Sci Rev, 29: 26-31, 2001.
13) Brown SH et al: Effects of abdominal muscle coactivation on the externally preloaded trunk: variations in motor control and its effect on spine stability. Spine, 31: E387-E393, 2006.
14) O'Sullivan PB et al: Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. Spine, 22: 2959-2967, 1997.
15) Panjabi MM: Clinical spinal instability and low back pain. J Electromyogr Kinesiol, 13: 371-379, 2003.
16) Kaeding CC et al: Management and return to play of stress fractures. Clin J Sport Med, 15: 442-447, 2005.
17) Patel DS et al: Stress fractures: diagnosis, treatment, and prevention. Am Fam Physician, 83: 39-46, 2011.
18) Mori S et al: Increased intracortical remodeling following fatigue damage. Bone, 14: 103-109, 1993.