Assessment of the trunk motion of scoliotic patients during lateral movement based on ultrasound motion analysis system

J. Y. Jung, C. M. Yang, and J. J. Kim

***Abstract*—**In this study, we determined the differences in angle variation between the location and direction of scoliotic patients during trunk lateral movement using ultrasound motion analysis system. 20 adolescents who diagnosed idiopathic scoliosis were divided into four groups according to their curve location and direction. Experimental procedure was divided into two sections: initial position, and left/right lateral bending position. To analyzed the alteration of the trunk motion, ultrasound markers were represented the segments and it refers to the lumbar, thoraco/lumbar, lower thoracic, and upper thoracic regions. In the results of this study, significant angle variations were shown in the lumbar and thoracic regions during left and right lateral bending for the scoliotic groups. In addition, differences in angle variation between left and right lateral bending decreased gradually and it was related to the compensatory movement of the trunk segments according to the curve magnitude defined as Cobb angle. From these results, we concluded that the location and direction of the curve in the scoliotic patients may be influence on dynamic trunk movement and postural balance in static and dynamic conditions. Furthermore, scoliosis ultrasound motions analysis system can be utilized to analyze the dynamic motion of trunk segments of idiopathic scoliosis patients in adolescence.

***Keywords*—**Adolescent idiopathic scoliosis, dynamic trunk motion, lateral trunk movement, postural balance, ultrasound motion analysis system.

I. INTRODUCTION

SPINE plays a critical role in keeping balance and stability of the human body under both static and dynamic conditions. Asymmetrical spinal loading distribution which is caused by deformation of the spine has been associated with excessive and progressive spinal curvature in idiopathic scoliosis. This abnormal spinal curvature is formed laterally to the right or left side with rotation of the vertebrae. Excessive curvature of the spine in the scoliotic patients group was significantly higher than in the control group during standing and sitting [1]. Progressive curve can negatively affect physical activity in adolescent [2]-[3]. Adolescent idiopathic scoliosis (AIS) which its pathogenesis remains unknown is the most common deformity occurring approximately 4 % of adolescents. Continued progression of the curve in the thoracic and lumbar spine may be exacerbated caused by rapid growth during adolescence. It is so crucial to determine accurately the types of spinal curvature for treating and preventing scoliosis. Accordingly, numerous researches for the understanding of idiopathic scoliosis have been emphasized the importance of early detection and protection for scoliosis during adolescence [4]-[8]. Because initial asymmetry due to lateral deformity of the spine leads to altered posture, asymmetrical trunk motion, and posture imbalance [6], [9].

There are many anatomical classifications based on the location of the curves such as Ponseti classification, Moe and Kettleson classification, King's classification, Lenke classification, Peking Union Medical College (PUMC) classification, Rigo's classification and Schroth classification. These classifications have been often used to describe and diagnosis for patients with scoliosis. Although differences in specific curve types between many methods exist, these categories are based primarily on apex location. The C-shaped curve refers to a single curve in the thoracic, lumbar, or thoracolumbar regions. Additionally, the S-shaped curve refers to a double curve which is located in the thoracic spine to the right and in the lumbar spine to the left side.

The Scoliosis Research Society (SRS) defined the diagnosis of scoliosis as an asymmetry on the Cobb angle ≥ of 10°. The cobb angle was defined as the angle between the most inclined vertebral end-plates at each end of the curve and used to quantify the magnitude of spinal curvature [11]. Cobb angle measurement is the "gold standard" of scoliosis evaluation in the medical fields. Generally, radiographic method is most widely used to assess the Cobb angle [12]. Regular radiographic evaluation is necessary process to confirm the presence of a potential spinal curvature and decide what treatment method is the best for scoliotic patients. However, it provided continuous radiation exposure which can induce cancer, tumors, cataracts, and potentially harmful genetic changes. In addition, this

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equipment can be also only used for static posture in a fixed location. Richards [13] reported that standing radiography showed limitations such as inter- and intra-observer variations ranged from 3 to 9 degrees. Therefore, more accurate and reliable systems than previous x-ray system are being developed to perform long-term monitoring without radiation hazard and measurement error by evaluating and treating spinal deformity.

It is very important to evaluate the location of the curve of patients with scoliosis in the coronal plane for providing appropriate treatment according to the curve progression for individuals. Measurement of the thoracic and lumbar spine movement is a useful indicator in identifying the main characteristics of scoliosis. Especially, ultrasound-based measurement system can be utilized to evaluate the movements of the thoracic and lumbar spine. The repeatability and reliability of this system using point marker was confirmed in previous study [14]. Although dynamic motions in the cervical, thoracic, and lumbar spine of the patients with spine disorder were measured using this system, it has not been utilized to assess the dynamic spine movement and trunk balance of scoliotic patients specifically with their curve types.

The purpose of this study was to investigate the differences in dynamic trunk movement between scoliotic patients with three different curve types during lateral bending to the left and right side using ultrasound-based motion analysis system.

II. METHODS & MATERIALS

A. Subjects

20 adolescents who were diagnosed idiopathic scoliosis from the Department of Rehabilitation Medicine of Chungnam National University Hospital in Daejeon, Republic of Korea, participated in this study. All subjects were divided into four sub-groups as follows: the control group (CG, n=5), the scoliosis group with right thoracic curve (SGRT, n=5), and the scoliosis group with left lumbar curve (SGLL, n=5), and the scoliosis group with right lumbar curve (SGRL, n=5). A posteroanterior full spine standing X-ray was conducted to calculate Cobb angle of the scoliotic patients. Subjects presenting with gait abnormalities, back pain, pelvic asymmetry greater than 1 cm, or surgical treatment for the scoliosis were excluded in this study. All adolescents and their parents were informed a full explanation regarding the protocol and provided written consent before their participation. The mean age, height, body weight, and Cobb angle of each group was shown in Table 1.

Table 1. Characteristics of subjects (Mean±SD)

	NG	Scoliotic Patients		
		SGRT	SGLL	SGRL
Age (years)	15.0±1.0	14.2±2.0	13.6±1.9	13.8±3.2
Height (cm)	166.8±6.3	157.8±8.2	151.8±3.6	156.3±5.4
Weight (kg)	63.6±6.9	47.0±6.9	44.8±6.1	49.8±13.5
Cobb angle (°)	-	18.0±9.6	16.7±3.1	19.4±8.4

B. Experimental Setup

Dynamic lateral trunk motion of subjects was assessed with the ultrasound-based motion analysis system CMS 20 (Zebris Medical GmbH, Isny, Germany). This system consists of 3 ultrasonic microphones (MA-XX), basic unit, and 6 ultrasonic markers (M1008), as shown in Fig. 1.

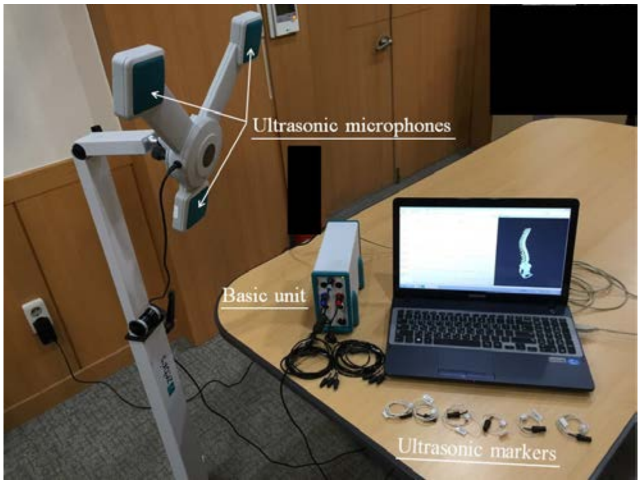

Fig. 1. Ultrasound-based motion analysis system

C. Experimental protocol

Six markers were attached to the skin of the back with adhesive tape. Before attaching markers, the skin was cleaned with alcohol. Marker 1 was attached between S1 and L5, and marker 6 was also attached between C7 and T12. Following this, marker 2-5 were positioned at equal distance from each other, as shown in Figure 2. For exact placement of the markers, subjects bent slightly forward when the marker was placing on. After attaching all markers, subjects were instructed to stand with upright posture.

Experimental procedure was divided into two sections: the initial position, and left/right lateral bending. First, in initial position, the head, shoulders, trunk, upper and lower extremities were positioned as in the standard standing position. And, finally, in left/right lateral bending, subjects were asked to perform maximally left and right lateral bending of the trunk for 5 seconds, respectively. All subjects were allowed to conduct a practice all testing procedure until they become familiar with this test.

D. Data Analysis

The alteration of the thoracic and lumbar spine alignment during lateral bending was analyzed using WinSpine software (Zebris Medical GmbH, Isny, Germany). This software consists of Section A and B. Section A shows the angle curve and coordination of the single marker. It calculates the angle variation according to the left and right direction during lateral trunk movement. And, Section B shows the animation of the total spine. The angle variation was presented in lateral local mobility. It was represented the segments that are described by the markers, as shown in Fig. 3.

(a)

(b)

(c)

Fig. 2. (a) Initial position; (b) left lateral bending; (c) right lateral bending

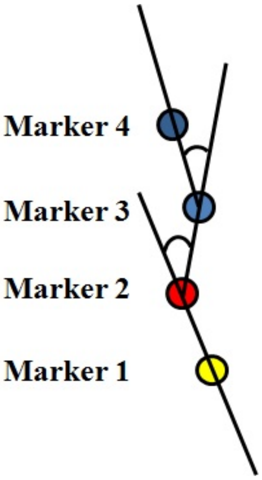

Fig. 3. Lateral local mobility calculation

All segments were classified with 4 regions. Each region was defined as: the region 1 (lumbar), region 2 (thoraco/lumbar), region 3 (lower thoracic), and region 4 (upper thoracic). Calculation method for analyzing the angle variation was as follows:

1. Draw a straight line between the marker 1 and marker 2, and this is a reference line to calculate the variation angle in the region 1.
2. Draw a straight line between the marker 2 and marker 3.
3. Measure the angle between two lines.

Statistical analysis was performed using SPSS PASW statics 18 software (SPSS Inc, Chicago, USA). A t-test was used to examine the differences in lateral mobility between the left and right side. Paired t-test was also used to compare the angle variation between the groups. Statistical significance was set at $p < 0.05$ level.

III. RESULTS

Differences in angle measurements between the groups during left and right lateral bending are presented in Fig. 4 and Table 2.

As compared with lateral local mobility among NG, SGRT, SGLL, and SGRL, all scoliosis groups showed more asymmetrical lateral bending patterns than NG according to their location and direction of the scoliotic curve.

In the region 1, SGRT and SGLL showed more increased angle variation during left lateral bending than right lateral bending. In contrast, SGRL showed more increased angle variation during right lateral bending than left lateral bending. There were significant differences in angle variation between left and right lateral bending when SGLL and SGRL performed lateral trunk movement corresponding with their location and direction of the curve ($p < 0.05$).

In the region 2, there was big difference in angle variation between left and right lateral bending in SGRT. SGRT showed more increased angle variation during right lateral bending than

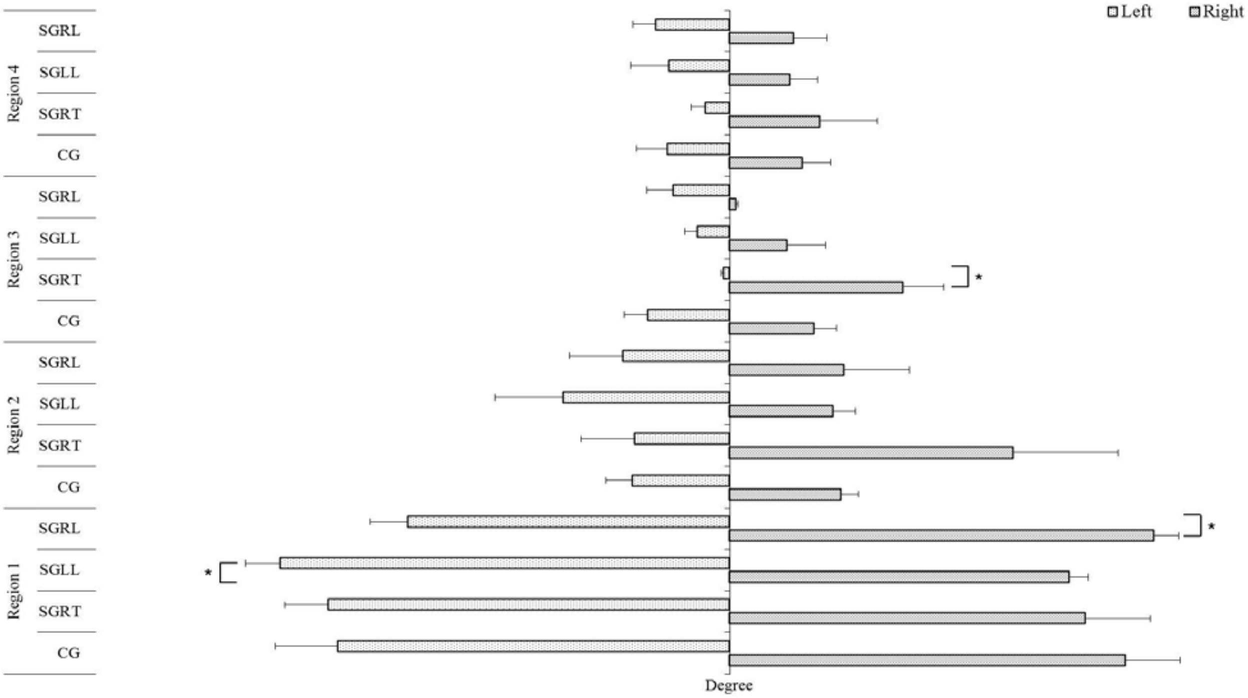

Fig. 4. Differences in angle variation between left and right lateral bending in all groups

Table 2. Differences in angle variation between left and right lateral bending in all groups

		CG	SGRT	SGLL	SGRL
Region 1	Left lateral bending	9.27±1.49	9.50±1.03	10.63±0.82*	7.61±0.90
	Right lateral bending	9.37±1.27	8.41±1.53	8.04±0.43	10.04±0.57
Region 2	Left lateral bending	2.30±0.64	2.24±1.28	3.95±1.61	2.53±1.27
	Right lateral bending	2.63±0.41	6.71±2.47	2.44±0.52	2.71±1.53
Region 3	Left lateral bending	1.93±0.58	0.14±0.06	0.76±0.31	1.34±0.63
	Right lateral bending	1.99±0.51	4.10±0.95	1.36±0.90	0.16±0.03
Region 4	Left lateral bending	1.47±0.74	0.58±0.33	1.44±0.91	1.75±0.54
	Right lateral bending	1.72±0.65	2.14±1.34	1.43±0.65	1.51±0.77

(Mean±SD), $^{*}p < 0.05$

left lateral bending. The variation of SGLL more increased during left lateral bending while SGRL showed more increased angle variation during right lateral bending. However, there were no statistical significances in angle variation between left and right lateral bending in all groups.

In the region 3, there was only significant difference in angle variation between left and right lateral bending in SGRT ($p < 0.05$). The angle variation of SGRT more increased during right lateral bending than left lateral bending. The opposite tendency was observed in both SGLL and SGRL. The angle variations of two groups increased to the opposite direction with their scoliotic curves, respectively.

In the region 4, SGRT showed more increased angle variation during right lateral bending than left lateral bending. However, CG, SGLL, and SGRL showed symmetrical patterns of angle variation relatively. There were no significant differences in angle variation between left and right lateral bending in all groups.

The maximum angle values during left and right lateral bending were presented in the region 1 for all groups. In addition, the angle variation patterns decreased gradually from the region 1 to region 4. Furthermore, there were no significant differences in angle variation between the groups during left and right lateral bending in all regions.

I. Discussion

To evaluate the differences in lateral dynamic trunk movement between the location and direction of the curve in patients with adolescent idiopathic scoliosis, we assessed the angle variation during left and right lateral bending using ultrasound-based motion analysis system.

From the results of this study, we confirmed that the location and direction of the scoliotic curve may influence directly on postural balance during left and right lateral bending. Previous research demonstrated the effects of the direction of the curve in scoliotic patients on asymmetrical postural balance during sitting. Scoliosis patients group showed more tilted body pressure distribution on the convex side than concave side [16]. Nault [17] identified decreased postural stability associated with spinal deformity during standing. This is consistent with the findings of this study. The angle variation of the thoracic and lumbar region in all scoliotic patients more increased than control group.

In this study, three groups with different location and direction of the curve were indicated asymmetrical lateral bending movements. Especially, SGLL and SGRL showed more increased angle variation significantly in accordance with their scoliotic curve in the region 1 which is defined as lumbar region. Additionally, the angle variation of SGRT more increased in the region 3 and region 4 that is defined as thoracic regions. It means that curve direction of the scoliotic patients is associated with asymmetrical range of motion during left and right lateral bending. It was suggested that asymmetrical postural balance was correlated with convexity and concavity of the spinal curve [18].

Generally, scoliosis curve can occur in the thoracic spine, lumbar spine, and or both areas at the same time [19]. Accurate diagnosis for the regions with scoliotic curvature is very important to evaluate the postural balance of patients and treat progression of the curve of adolescence. This study investigated the dynamic trunk motion for patients with right thoracic, and left or right lumbar scoliosis. To assess the dynamic postural balance, ultrasound markers which attached to the skin in patients with scoliosis were represented the segments, and then it was classified with 4 regions. All regions were defined as: region 1 (lumbar), region 2 (thoracolumbar), region 3 (lower thoracic), and region 4 (upper thoracic). The results showed that the highest angle difference was presented in the region 1 for the scoliosis group compare to other regions. Furthermore, angle differences between left and right side were decreased gradually from the region 1 to region 4. Subjects which were participated in this experiment have right thoracic curve and left or right lumbar curve. This indicated that the region of scoliotic curvature may affect dynamic trunk movement, and it was related to the postural balance of adolescent idiopathic scoliosis patients [20].

In the region 1 and region 2, the angle variation of SGLL and SGRL were more increased during left and right lateral bending, respectively. However, these asymmetrical movement patterns were changed to the opposite tendency in the region 3. SGRT showed increased angle variations in the region 2 and region 3 corresponding with location and direction of the curve while opposite movement pattern was presented in the region 1 during left and right lateral bending. We suggested that this was compensation of the body for maintaining posture and balance correctly. Especially, compensation strategy of SGRL showed consistent aspect from the region 2 to the region 1 unlike SGLL. This indicated that more evident compensatory strategy may be necessary to maintain postural balance between the upper and lower trunk segments against spinal curvature with large curve magnitude in the coronal plane which was defined by Cobb angle.

II. CONCLUSION

The purpose of this study was to determine the differences in angle variation of scoliosis groups which was classified with the location and direction in the thoracic and lumbar region during left and right lateral bending. From the results of this study, it was concluded that the location and direction of the curve in the scoliotic patients may be influence on postural balance continuously in static and dynamic conditions.

Furthermore, we suggested that ultrasound-based motion analysis system can be used to analyze the dynamic trunk motion of the patients with idiopathic scoliosis and provide the information about postural balance related to the location and direction of the curve.

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REFERENCES

[1] M. K. Ireneusz, P. F. Halina, S. Piotr, Z. S. Katarzyna, D. Aneta, K. Marek, and R. Juozas, “Analysis of the sagittal plane in standing and sitting position in girls with left lumbar idiopathic scoliosis,” *Pol Ann Med.*, vol. 21, no. 1, pp. 30-34, Sept. 2013.

[2] J. W. Kouwenhoven and R. M. Castelein, “The pathogenesis of adolescent idiopathic scoliosis: review of the literature,” *Spine.*, vol. 33, no. 26, pp. 2898-2908, Dec. 2008.

[3] C. Fortin, D. E. Feldman, F. Cheriet, D. Gravel, F. Gauthier, and H. Labelle, “Reliability of a quantitative clinical posture assessment tool among persons with idiopathic scoliosis,” *Physiotherapy.*, vol. 98, no. 1, pp. 64-75, Mar. 2012.

[4] S. Sahli, H. Rebai, S. Ghroubi, A. Yahia, M. Guemazi, and M. H. Elleuch, “The effects of backpack load and carrying method on the balance of adolescent idiopathic scoliosis subjects,” *Spine J.*, vol. 13, no. 12, pp. 1835-1842, Dec. 2013.

[5] K. S. Suk, J. H. Baek, J. O. Park, H. S. Kim, H. M. Lee, J. W. Kwon, S. H. Moon, and B. H. Lee, “Postoperative quality of life in patients with progressive neuromuscular scoliosis and their parents,” *Spine J.*, vol. 15, no. 3, p. 446-453, Mar. 2015.

[6] A. V. Bruyneel, P. Chavet, G. Bollini, and S. Mesure, “Gait initiation reflects the adaptive biomechanical strategies of adolescents with idiopathic scoliosis,” *Ann Phys Rehabil Med.*, vol. 53, no. 6, pp. 372-386, Aug-Sept. 2010.

[7] M. de Sèze, and E. Cugy, “Pathogenesis of idiopathic scoliosis: a review,” *Ann Phys Rehabil Med.*, vol. 55, no. 2, pp. 128-138, Mar. 2012.

[8] M. A. Asher, and D. C. Burton, “Adolescent idiopathic scoliosis: natural history and long term treatment effects,” *Scoliosis.*, vol. 1, no. 1, pp. 2, Mar. 2006.

[9] G. Gur, B. Dilek, C. Ayhan, E. Simsek, O. Aras, S. Aksoy, and Y. Yakut, “Effect of spinal brace on postural control in different sensory conditions in adolescent idiopathic scoliosis: a preliminary analysis,” *Gait Posture.*, vol. 41, no. 1, pp. 93-99, Jan. 2015.

[10] J. E. Lonstein, “Scoliosis: surgical versus nonsurgical treatment,” *Clin Orthop Res.*, vol. 443, no. 1, pp. 248-259, Feb. 2006.

[11] I. A. Stokes, "Three-dimensional terminology of spinal deformity. A report presented to the Scoliosis Research Society by the Scoliosis Research Working Group on 3-D terminology of spinal deformity," *Spine.*, vol. 19, no. 2, pp. 236-248, Jan. 1994.

[12] I. A. Stokes, and D. D. aronsson, "Computer-assisted algorithms improve reliability of King classification and Cobb angle measurement of scoliosis," *Spine.*, vol. 31, no. 6, pp. 665-670, Mar. 2006.

[13] B. S. Richards, R. M. Bernstein, C. R. D´Amato, and G. H. Thompson, "Standardization of criteria for adolescent idiopathic scoliosis brace studies: SRS Committee on Bracing and Nonoperative Management," *Spine.*, vol. 30, no. 18, pp. 2068-2075, Sept. 2005.

[14] C. Fölsch, S. Schlöqel, S. Lakemeier, U. Wolf, N. Timmesfeld, and A. Skwara, "Test-retest reliability of 3D ultrasound measurements of the thoracic spine," *PM R.*, vol. 4, no. 5, pp. 335-341, May. 2012.

[15] S. Prange, A. Schmitz, D. Schulze-Bertelsbeck, T. Wallny, G. Schumpe, and O. Schmitt, "Ultrasound topemetric measurements of thoracic kyphosis and lumbar lordosis in school children with normal and insufficient posture," *Z Orthop.*, vol. 140, no. 2, pp. 160-164, Mar-Apr. 2002.

[16] J. Y. Jung, S. K. Bok. B. O. Kim, Y. W, and J. J. Kim, "Effects of the direction of the curve in adolescent idiopathic scoliosis on postural balance during sitting," *Proc. 14th Int. Conf. on Circuits, Systems, Electronics, Control & Signal Processing*, 2015, pp. 19-23.

[17] M. L. Nault, P. Allard, S. Hinse, R. Le Blanc, O. Caron, H. Labelle, and H. Sadeghi, "Relationship between standing stability and body posture parameters in adolescent idiopathic scoliosis," *Spine.*, vol. 27, no. 17, pp. 1911-1917, Sept. 2002.

[18] J. Timgren and S. Soinila, "Reversible pelvic asymmetry: An overlooked syndrome manifesting as scoliosis, apparent leg length difference, and neurologic symptoms," *Churchill Livingstone*, London, 2002.

[19] N. M. Hebela, and P. J. Tortolani, "Idiopathic scoliosis in adults: classification, indications, and treatment options," *Spine.*, vol. 21, no. 1, pp. 16-23, Mar. 2009.

[20] J. Y. Jung, E. J. Cha, K. A. Kim, Y. W, S. K. Bok, B. O. Kim, and J. J. Kim, "Influence of pelvic asymmetry and idiopathic scoliosis in adolescents on postural balance during sitting," *Bio-Med Mater Eng.*, vol. 26, no. 1, pp. S601-S610, 2015.

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