Magnetic Resonance Imaging Demonstrates Lack of Precision in Needle Placement by the Infraclavicular Brachial Plexus Block Described by Raj Et Al.

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The infraclavicular brachial plexus block first described by Raj et al. was supposed to anesthetize all the main peripheral nerves of the brachial plexus without the risk of pneumothorax. However, in performing the block, we have had difficulties finding the nerves at the cord level. Therefore, we questioned whether the recommended needle direction (the "Raj line") guides the needle close enough to the cords. We therefore designed an anatomic study to answer this question and to assess the risks of entering the pleura and axillary vein. Ten volunteers were examined noninvasively in an open model magnetic resonance scanner. The Raj line deviated greatly from a defined location on the cords by a mean of 26 (range 14-39) mm, always caudad, and posterior to the target in nine cases. Further, the needle trajectory's shortest distance to the pleura was only 10 (0-27) mm, and in one case, it hit the pleura. Finally, the Raj Line's distance to the axillary vein was also short, 11 (0-18) mm. We conclude that a modification of the method is necessary to guide the needle closer to the cords and further away from the pleura and the axillary vein. A more lateral needle insertion seems beneficial. Implications: Using a magnetic resonance scanner, the anatomical basis of Raj's infraclavicular method for brachial plexus blockade was examined in volunteers. The results show that the method should be modified to make it more precise and to provide less risk of complications.

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The axillary and musculocutaneous nerves are difficult to anesthetize using the axillary brachial plexus approach because of their proximal takeoff (1). The infraclavicular technique described by Raj et al. (2) was designed to avoid this difficulty by blocking all the main terminal nerves with minimal or no risk of pneumothorax. Additional advantages of this method include blockade of the intercostobrachial nerve and the ability to perform the block with the arm in any position.

The target for local anesthetic injection by using Raj et al.'s method is the cord level of the brachial plexus proximal to the formation of the five main terminal nerves: the axillary, musculocutaneous, radial, median, and ulnar nerves. The cords are located between the outer border of the first rib and the lateral border of the pectoralis minor muscle (Fig. 1). Beneath this muscle, the cords embrace the axillary artery longitudinally, surrounding the artery according to their names: the lateral, posterior, and medial cords. The axillary vein is positioned caudad to the artery. Using the infraclavicular method described by Raj et al. (2), the patient is supine with the arm preferably abducted to 90°. The point of needle insertion is 2.5 cm below the inferior border of the clavicle, either on a paramedian line through the point at which the subclavian artery is palpated dipping under the clavicle or, alternatively, on a paramedian line through the midpoint of the clavicle. The needle is directed laterally toward the brachial artery at an angle of 45° to the skin, the "Raj line." A nerve stimulator aids in exact positioning of the needle. The method does not specify toward which part of the palpable brachial artery the needle should be directed. In the present study, we chose the point at which the lateral border of the pectoralis major muscle crosses the brachial artery.

Except for the original article by Raj et al. (2), we found no references describing clinical experience with the method. Raj et al. (2) reported a success rate of approximately 95% in >200 patients ("success" was not defined) and that the danger of penetrating blood vessels was the same as that using other approaches. In our experience, however, it has often been necessary to redirect the needle several times to obtain an

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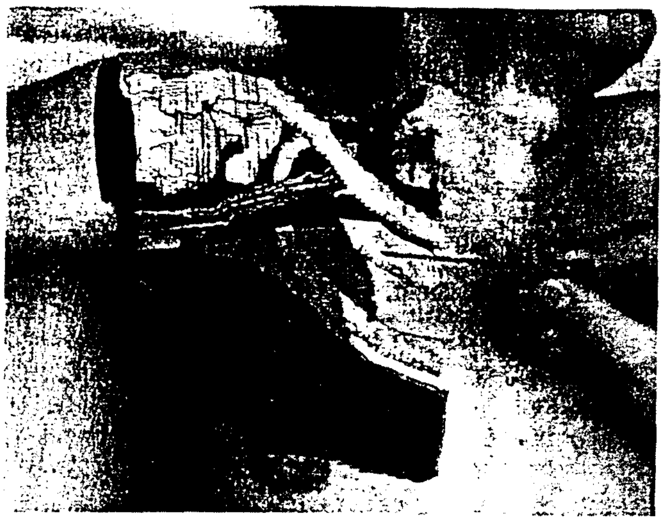

Figure 1. Front view of infraclavicular anatomy, right side, illustrated by segmented magnetic resonance images merged with a correlated surface picture of the identical person. Note the clavicle and the two first costae. The coracoid process with an adjacent small lateral part of the scapula is seen medial to caput humeri. The axillary artery is found cephalad to its accompanying vein, the vein with a larger diameter than the artery. Longitudinally, the artery is embraced by the cords of the brachial plexus. The pectoralis major muscle (dark area) and the pectoraiis minor muscle (gray area) are presented only with the parts caudad to the axillary vein. A needle is positioned according to Raj's infraclavicular method to block the brachial plexus, with the tip of the needle at the skin entry site.

appropriate motor response with the nerve stimulator. We therefore questioned whether the recommended needle direction brings the needle close enough to the brachial plexus. Because the brachial plexus is easily demonstrated by magnetic resonance imaging (MRI) with direct multiplanar imaging capability and superior soft-tissue resolution (3), we designed a MRI study of the relevant anatomy and the needle trajectory of Raj's method on volunteers. To determine the risk of pneumothorax and axillary vein puncture, the distances from the needle trajectory to the pleura and axillary vein were also measured. Finally, we assessed whether two landmarks described by Raj et al. for derivation of the needle entry point (the point at which the subclavian artery is palpated dipping under the clavicle and the midpoint of the clavicle) are interchangeable.

Methods

After approval of the protocol by the regional ethical committee, 10 healthy volunteers (Table 1) gave their written, informed consent for MRI of their brachial plexus anatomy. The volunteers were examined in an open MRI scanner (4), without the use of any needle. With the open design of the scanner, it was possible to position the volunteers exactly as if they were to receive an infraclavicular block, with the arm abducted

Table 1. Demographic Data

Volunteer	Gender	Age (yr)	Height (cm)	Weight (kg)
1	M	51	186	102
2	F	44	160	50
3	M	25	193	80
4	M	26	176	67
5	F	26	164	55
6	M	26	182	82
7	F	27	163	50
8	F	24	170	60
9	F	25	172	60
10	M	27	180	70
Mean ± SD		30 ± 9	175 ± 11	68 ± 16
Range		24–51	160-193	50–102

at 90". Sagittal images were obtained using three-dimensional T_1-weighted gradient echo sequence; from these images, multiplanar coronal and axial images were reconstructed. The scanning parameters were: TR/TE 34/15, flip angle 60°, slice thickness 2 mm, matrix 120 × 256, FOV 240 X 320, receive bandwidth 12, NEX 1, and number of slices 124. This resulted in a total scanning time of 8 min 46 s.

To simulate and evaluate the needle advancement using Raj's infraclavicular method in the three-dimensional MRI of each volunteer, three anatomical key points were determined in the images. These points were the point of needle insertion, the final position of the needle point, and a target. The first two points were defined according to Raj's method; the third was defined for the present study. The Raj line is the line between the point of needle insertion and the final position of the needle point. Other lines and points in the study model aid in defining the three key points. The points were determined in coronal (frontal), sagittal (paramedian), and axial (transverse) planes, examples of which are shown for Volunteer 9 (Figs. 2– 4).

The target had to be on the cords and defined in a standardized fashion. To achieve this, the position of two anteroposterior lines in coronal planes were marked (Fig. 2). The first line abutted the superior border of the clavicle and went through the midaxis of the subclavian artery. This line was assumed to pass through the point at which the subclavian artery is palpated dipping under the clavicle. The second line went through the junction of the brachial artery (its midaxis) and the lateral edge of the pectoralis major muscle. This line was expected to pass through our defined palpable point of the brachial artery. A sagittal plane was then constructed through the point at which a perpendicular line from the most anterocaudad point of the coracoid process hit the plane between the two described anteroposterior lines.. The target was defined as the middle point of all nerve

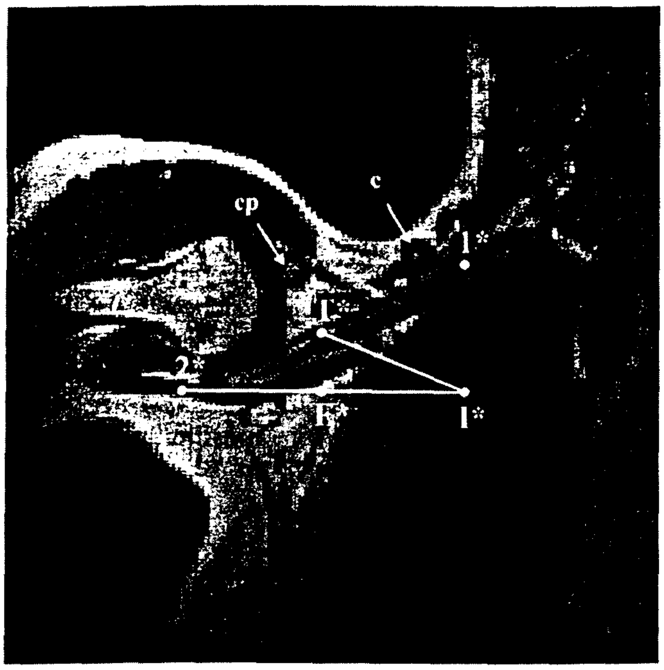

Figure 2. Coronal magnetic resonance image, right side (Volunteer 9). The large, dark, central area of, the picture is the right lung. The axillary artery is depicted in almost its complete length, whereas only a shorter distal part of the corresponding vein is seen caudad to the artery. Only one of the cords, above the artery, is distinctly discernible in this image. A cross-section of the clavicle (c), is seen lateral to the artery. The coracoid process (cp) is located medial to the superior aspect of caput humeri. The following symbols' positions are marked by white bullets, not by the asterisks. T = defined target on the cords of the brachial plexus, I = point of needle insertion, F = final position of the needle point *once the* simulated needle was advanced according to Raj's method, 1 = point at which the subclavian artery is palpated dipping under the clavicle, 2 = point at which the brachial artery is palpated at the junction with the lateral border of the pectoralis major muscle. None of the five described points are located in the given coronal image. However, their anteroposterior projections to this coronal image are marked as T*, I*, F*, 1*, and 2*, respectively. The needle direction recommended by using Raj's method (the "Raj line") is projected to the present coronal plane as line I'-2'. I*-T* = corrected needle direction.

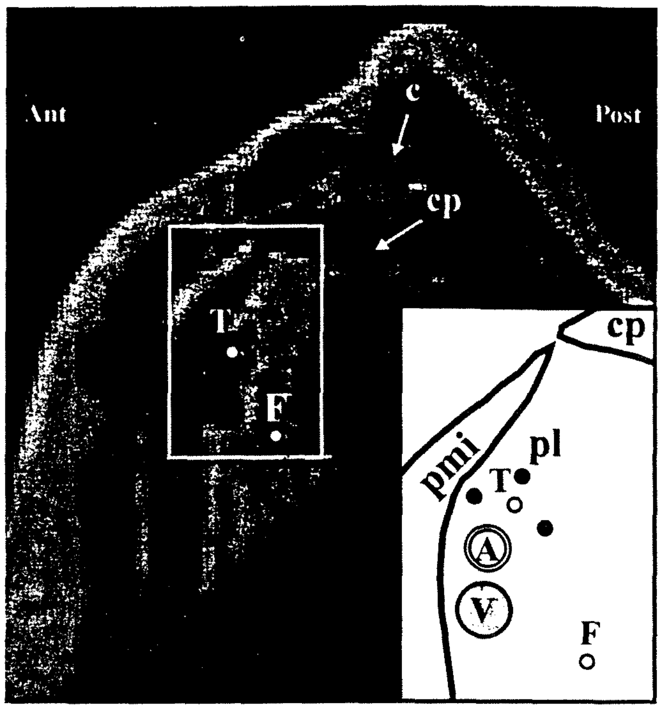

Figure 3. Sagittal magnetic resonance image, right side (Volunteer 9). An illustration from a magnified part of the image is in the right lower comer. Ant = anterior, Post = posterior. The clavicle (c) and the coracoid process (cp) are indicated by arrows. The image goes through a defined target (T; the middle point of all nerve structures around the artery) on the cords. The final position of the needle point (F) is defined as the point at which the needle direction recommended by Raj's method (the "Raj line") hits this plane. T and F are represented in their true positions and are marked by white bullets. The black bullets show the position of the three cords of the brachial plexus (pl) posterior to the pectoralis minor muscle (pmi) and caudad to the cp. The cords are positioned cephalad to the artery (A), which is cephalad to the axillary vein (V). In this sagittal plane, the Raj line's distance to axillary vein wall was measured, and the true distance between T and F could be controlled.

structures around the artery in this sagittal plane (Fig. 3).

The needle insertion point was determined primarily by constructing a sagittal plane through the defined anteroposterior line in the subclavian artery. In this plane, a point 25 mm below the inferior border of the clavicle was marked. The anterior projection of this point to the skin surface then defined the needle entry point (Fig. 2).

The final position of the needle point was determined where the Raj line hit the sagittal plane through the defined target. The Raj line was defined by the crossing of two planes, of which the first went through the needle insertion point and the defined anteroposterior line in the brachial artery. The second plane was derived in the axial plane after drawing two lines through the needle insertion point: the first line tangentially to the skin and the other 45" to the tangent, posterolaterally (Fig. 4). The plane perpendicular to the axial plane through the 45" line was the second plane defining the Raj line.

The two referred landmarks were determined in coronal planes. The point at which the subclavian artery is palpated dipping under the clavicle was taken as the junction of the subclavian artery (its midaxis) and the superior border of the clavicle. The midpoint of the clavicle was defined as the midpoint of the distance between the laterocephalad and mediocephalad ends of the clavicle.

The deviation of the Raj line from the target was measured both by distance and angle in the coronal and axial planes. The true distance between the points was calculated using the measurements in axial and coronal planes and could be controlled by direct measurement in the sagittal plane through the defined target. To better evaluate these measurements, the simulated needle depth (the length of the needle beneath the skin) before and after redirection of the needle was also measured in axial planes.

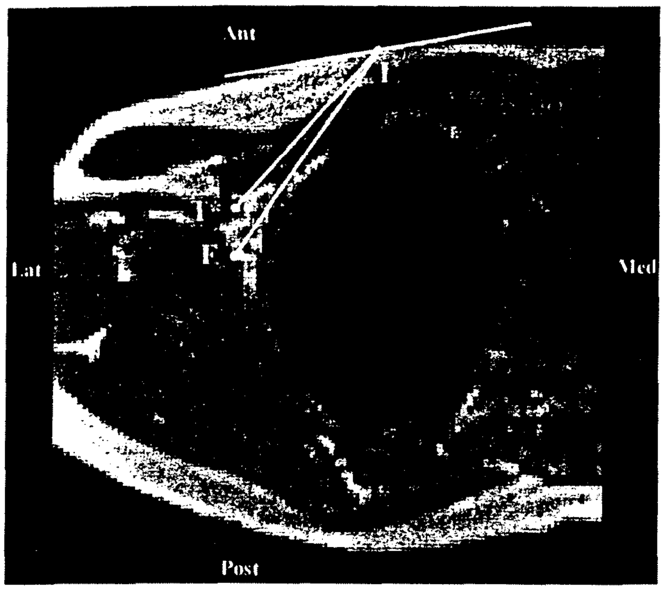

Figure 4. Axial magnetic resonance image, right side, seen from below (Volunteer 9). Ant = anterior, Post = posterior, Lat = lateral, Med = medial. The large central, dark, rounded area is the right lung. Three points to be described are marked by white bullets. The plane goes through the point of needle insertion (I). By coincidence, the final position of the needle point (F) is also found in the same axial plane in this volunteer. However, the defined target (T) on the cords is cephalad to the present axial plane. T* = the caudad projection of T. The needle direction recommended by Raj's method (the "Raj line") is the line I-F, 45" to the skin. The corrected needle direction in the axial plane (I-T) is anterior to the Raj line in this volunteer by 7°.

The shortest distance from the Raj line to the pleura was controlled in axial planes between the needle insertion point and the final position of the needle point.

The distance from the final position of the needle point to the nearest axillary vein wall (posterior or anterior vein wall) was measured in the sagittal plane through the defined target.

The distance between two landmarks (where the subclavian artery dips under the clavicle and the midpoint of the clavicle) was measured in coronal planes.

The results are presented as means ± SD or means (range).

Results

The trajectory of the needle direction recommended by Raj et al. (2) deviated from our target on the cords by 26 (14-39) mm (Table 2). To reach the target a cephalad redirection of the needle (in the coronal plane) by 17 (12-25) mm or 17 (13–21)° was necessary in all the volunteers. In the axial plane, the Raj line deviated by 18 mm or 10° from the target, with a larger range of deviation than in the coronal plane: from 9 mm or 4° anterior to 30 mm or 17" posterior to the target. Only in Volunteer 1 did the needle direction pass on the anterior side of the target. In the remaining nine volunteers, the needle trajectory passed posterior to the target by 19 (7-30) mm or 11 (5-17)". Although the imprecision of the Raj line is similar in the coronal and axial planes when measured in millimeters, it is larger in the coronal than the axial plane when measured in degrees. These seemingly discrepant results are caused by the projection of the needle being shorter in the coronal than the axial plane.

The deviation of the Raj line in the axial plane implies that the target could be reached in this plane by a mean needle angle to the skin of 35 (28-49)"; that is, by a mean of 10" less than that recommended in Raj's method. The length of the simulated needle beneath the skin before and after repositioning was considerable, with mean values of 81 and 70 mm, respectively.

The shortest mean distance between the needle trajectory and the pleura was 10 (O-27) mm. In Volunteer 2 (female, 160 cm tall, weighed 50 kg), the needle would have touched the pleura. In seven other volunteers, the distance was ≤10 mm.

At the sagittal level of our defined target, the mean distance of the needle course from the axillary vein (either its posterior or anterior part) was of 11 (O-18) mm. In Volunteer 8, the Raj line touched the posterior wall of the vein. Only in Volunteer 1 did the needle trajectory pass on the anterior side of the vein (by 3 mm). Among the remaining eight volunteers, the Raj line passed posterior to the vein in the space between the vein and the pleura. In five of these eight volunteers, the simulated needle passed within 15 mm of the posterior vein wall.

The midpoint of the clavicle was found lateral to the crossing of the subclavian artery with the superior border of the clavicle by 17 (9-23) mm. Only in Volunteer 4 was the distance <10 mm.

Discussion

On average, the Raj line deviated from the target by 26 mm in the caudad-posterior direction, which fits our clinical observations. Patient anatomic variability may contribute to difficulties in finding the cords with the needle. The additional needle passes required are uncomfortable and may increase the risk of complications, especially of pneumothorax and vessel puncture. Finally, the time for performance of the block is prolonged. Therefore, our findings strongly suggest a modification of Raj's method, either as to the point of needle insertion or needle direction.

Our study further demonstrates that the method carries a risk of pneumothorax. A needle angle to the skin of 35" can hit the cords. However, with the range of this angle, there may be uncertainty as to when the needle is steep enough, as seen in our volunteers. If the nerves are not found because of an imprecise

Table 2. Results

Volunteer	Deviation (mm) Sagittal	Deviation (mm) Coronal[a]	Deviation (mm) Axial[b]	Deviation (°) Coronal[a]	Deviation (°) Axial[b]	Needle depth (mm) Before	Needle depth (mm) After	Pleura (mm)	Vein (mm)[c]	Landmarks (mm)[d]
1	22	19	9	17	4	79	84	27	3	14
2	25	14	20	14	13	76	64	0	15	14
3	39	25	30	21	17	90	71	8	16	16
4	34	19	27	20	15	85	69	6	18	9
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23
7	14	12	7	13	5	71	65	9	3	15
8	16	14	7	15	5	67	63	14	0	11
9	22	16	14	18	7	84	73	7	11	21
10	26	18	18	17	10	80	68	10	9	19
Mean ± SD	26 ± 6	17 ± 4	18 ± 9	17 ± 3	10 ± 5	81 ± 9	70 ± 7	10 ± 7	11 ± 7	17 ± 5
Range	14–39	12-25	7-30	13-21	4-17	67-98	63-84	0-27	0-18	9-23

[a] In all cases, the needle was deviated caudally to the target.
[b] The results are presented by their absolute values. Except for Volunteer 1, the needle direction was posterior to the target. In Volunteer 1, the needle passed 9 nun anterior to the target and required a 4” posterior redirection to hit the target. The required needle angle to the skin in the axial plane to bit the target may be calculated by subtracting the degrees in the Deviation Axial (°) column from the method-recommended 45” for Volunteers Z-10, then adding the degrees for Volunteer 1.
[c] In Volunteer 8, the simulated needle hit the posterior vein wall. In Volunteer 1, the needle passed 3 mm anterior to the vein. In the remaining eight volunteers, the needle course was posterior to the vein.
[d] In all volunteers, the midpoint of the clavicle was lateral to the point at which the subclavian artery dipped under the clavicle.

needle position in the coronal plane, deeper insertion could result in pneumothorax.

The risk of hitting the axillary vein is also evident from our study. Compression of the bleeding point and evaluation of the hematoma size are difficult in this location because of the presence of the pectoralis major and minor muscles between the skin and the vessel. The danger of hitting the axillary vein with a needle has not been documented in the literature. However, we think that, by using an optimal infraclavicular method, the risk of puncturing vessels should be as small as possible to avoid at least theoretical risks from a hematoma (e.g., local tenderness, discoloration, nerve injury, and compromised regional circulation).

We expect a nerve stimulator to induce motor stimulation of the nerves before the needle touches the arterial wall. Therefore, measurements to determine the relationship between the needle and the axillary artery were not performed.

The finding that the midpoint of the clavicle is located lateral (17 mm) to where the subclavian artery dips under the clavicle indicates that these reference points are not interchangeable for clinical purposes.

One may maintain that the accuracy of needle placement is not so important as long as the injection of local anesthetic is still inside the fascial sheath of the brachial plexus. However, the question of how freely the local anesthetic spreads within the fascial sheath is still unsettled (1). Performing the blocks with the aid of a nerve stimulator, we strive for a needle point position yielding a motor response from a brachial plexus nerve by an amperage of ≤0.5 mA with an impulse duration of 0.1 ms. Although data in humans are lacking, such a setting probably corresponds to a distance of only a few millimeters, if that, between the needle point and the stimulated nerve (5). From this perspective, it seems unsatisfactory to use a method with an imprecision of >20 mm.

Further, the selection of our target for the direction of the needle should be considered. If the target had been chosen at a more proximal point on the cords, the Raj line would have deviated even more in the coronal plane. By contrast, a more distal (lateral) target would have yielded less imprecision in the coronal plane. However, a more distal target could end in an area that may be more easily reached by using an axillary approach (6). Taken together, we think that the target selected in our model is appropriate for controlling the infraclavicular method described by Raj et al.

There are several other infraclavicular methods of clinical interest (7-10). None of them has been studied using MRI. The method of Moorthy et al. (9) positions the point of needle insertion above the clavicle, but the needle point ends up in the infraclavicular area. However, we considered it rational first to study the original method of Raj et al. (2) because it was the first modem infraclavicular method and is probably the principle inspiration for variant infraclavicular techniques. Our ultimate goal is to find an infraclavicular method that seems anatomically precise using MRI and that has little risk of complications.

According to unpublished information from Raj (ASRA meeting, San Diego, CA, 1996), he has changed his point of needle insertion to be on a line between the pulsation of the subclavian and the brachial artery and 2.5 cm from this line's crossing with the inferior border of the clavicle. As before, the needle is directed toward the brachial artery at an angle of 45° to the skin. This modified approach seems rational, making the insertion point more lateral and bringing the needle in a line that roughly corresponds to the course of the brachial plexus. We expect the modified method to be more precise in hitting the cords of the brachial plexus and to carry less risk of complications than the original method. However, this should be confirmed in a MRI study.

In conclusion, our MRI findings suggest that the difficulties we had in finding the nerves by using Raj et al.'s original infraclavicular method were caused by the method being too anatomically imprecise. The simultaneous risks of pneumothorax and axillary vein puncture also make a modification of the method necessary. Bringing the needle insertion point more lateral, as in Raj's modification of the infraclavicular block, probably represents a major improvement.

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