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Neurosurg Clin N Am 18 (2007) 215–222

NEUROSURGERY
CLINICS
OF NORTH AMERICA

# Radiographic Evaluation of Spinal Deformity

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It is more than 40 years ago that Dr. Harrington [1,2] introduced spinal instrumentation to the care of spinal deformity. Since then, the field of spinal surgery has witnessed rapid advancements in surgical techniques and options [3–8]. Proper evaluation and comparison depend on various process measures that can detect and assess change, as well as on outcome measures that report patient function and satisfaction. Ideally, process measures should also be strongly correlated with outcomes measures.

Inherent in the complete evaluation of patients with spinal deformity is a comprehensive radiographic evaluation in addition to other necessary radiographic studies, such as MRI, CT, and CT-myelography. As such, these more advanced imaging techniques are unable to capture coronal and sagittal balance, regional spinal deformities, and overall patient ''posture'' properly, especially standing. This radiographic evaluation includes process measures (radiographic measurements), which are determined from standing full-length (36-in) anteroposterior (AP) or posteroanterior (PA) and lateral radiographs (Fig. 1A, B), also known as ''scoliosis'' radiographs. In addition to these films, supine side-bending radiographs are frequently included to evaluate regional coronal curves for structural characteristics, instability, and balance, especially when operative intervention is contemplated (Fig. 1C, D). A 36-in supine lateral or hyperextension lateral radiograph over a bolster may also be indicated and is particularly helpful in evaluating the patient with kyphosis. On occasion, a spot lateral radiograph of the lumbosacral junction or a Ferguson view of this region is also necessary. Nonetheless, this article primarily reviews the standard radiographic methodology for obtaining reproducible radiographs for spinal deformity and the reliability of various deformity measurements and provides a brief introduction to classification strategy for clinical decision making.

## Radiographic methodology

Reproducible high-quality scoliosis radiographs are sometimes difficult to achieve, especially with variably skilled radiologic technicians and machines. The onset of digital radiographs has further brought this matter to the forefront, because most institutions are unable to capture single-shot long-cassette digital films. More commonly, two 14-in × 17-in radiographs are obtained and then ''stitched'' together to reproduce a digital scoliosis radiograph. This can introduce human error in matching as well as image distortion. Consequently, physicians should carefully monitor these techniques when evaluating scoliosis radiographs.

## Obtaining reproducible radiographs

A high-quality diagnostic film necessarily includes the cervicothoracic junction proximally and the pelvis distally. This permits a complete spine evaluation while also identifying pelvic parameters and spinal balance. The radiograph should be taken 72 in from the patient, and it must include a compensating filter to ensure that proper bony density is maintained to view various aspects of the spine. Numerous generations and models of grid ratios, film and screen combinations, and radiographic machine generators as well as patient size and shape preclude

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doi:10.1016/j.nec.2007.01.009

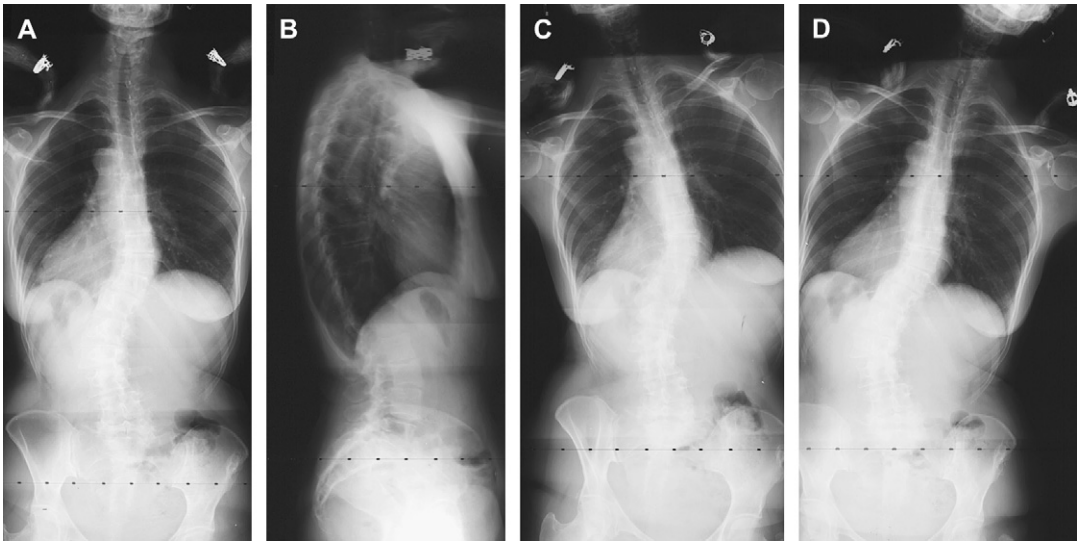


Fig. 1. Standard AP (*A*), lateral (*B*), and left- (*C*) and right (*D*) side-bending radiographs of a 62-year-old woman with degenerative lumbar scoliosis and spinal stenosis.


Fig. 2. Proper patient postioning for standing full-length radiographs in the front (*A*) and side (*B*) views. (*From* O'Brien MF, Kuklo TR, Blanke KM, et al. Spinal deformity radiographic measurement manual. Memphis (TN): Medtronic Sofamor Danek USA; 2004. p. 13; with permission.)

recommending standardized film exposure techniques or settings.

As noted earlier, the AP (or PA) and lateral films should be taken in the upright position with the knees extended, the feet placed shoulder width apart, and the patient looking straight ahead with the elbows bent and knuckles in the supraclavicular fossa bilaterally (Fig. 2) [9,10]. This places the arms at approximately 30° to 45° and helps to keep the humerii forward, thus facilitating visualization of the upper thoracic region on lateral radiographs. As well, this does not unnaturally lean the patient backward. If a limb length discrepancy of greater than 2 cm is present, a heel lift or block should be placed under the short extremity to level the pelvis for the AP view [10]. Supine side-bending (left and right) radiographs are also obtained when coronal deformity is present and are used to evaluate the flexibility of the various curves. These are generally used only for preoperative planning and are not routinely obtained. For adult scoliosis, this technique may assist in evaluating the ability to correct degenerative lumbar scoliosis posturally. For younger patients, proximal and distal fusion levels are identified or confirmed from these views.

## Reliability analysis

Valid process measures are also necessary to assess the effect of various interventions, or lack of interventions, and to permit comparisons. Knowing this reliability and reproducibility allows us to determine if the effect of the intervention is greater than the variability of the measurement itself; in other words, if the effect of the intervention as assessed by the process measure is greater than might be expected by chance attributable to the obligatory repetition of the measurement [11]. As such, process measures must be valid, discrete, and independently verifiable points that permit serial assessment to detect change.

The various radiographic measurements standard in the evaluation of spinal deformity have been validated [11]. Specifically, a rigorous evaluation of 17 measurements was obtained for each of 30 complete sets of full-length standing radiographs (preoperative AP, lateral, left and right side-bending, and postoperative AP and lateral radiographs, for a total of 180 films) by three fellowship-trained spinal deformity surgeons on two separate occasions (7020 data points).

These included the coronal Cobb measurement of the proximal thoracic (PT), main thoracic (MT), and thoracolumbar-lumbar (TL-L) curves (Fig. 3); apical vertebral translation (AVT) (Fig. 4); coronal balance (Fig. 5); T1 tilt angle (Fig. 6); lowest instrumented vertebra (LIV) tilt angle; coronal angulation of the disc below the LIV; and Risser grade. Apical rotation was also determined from the AP radiographs using the Nash-Moe technique in addition to the coronal major Cobb curve on supine side-bending radiographs. On standing preoperative and postoperative lateral radiographs, the sagittal Cobb curve for T2-T5, T5-T12, T2-T12, T10-L2, T12-S1, and sagittal balance (Fig. 7) were determined.

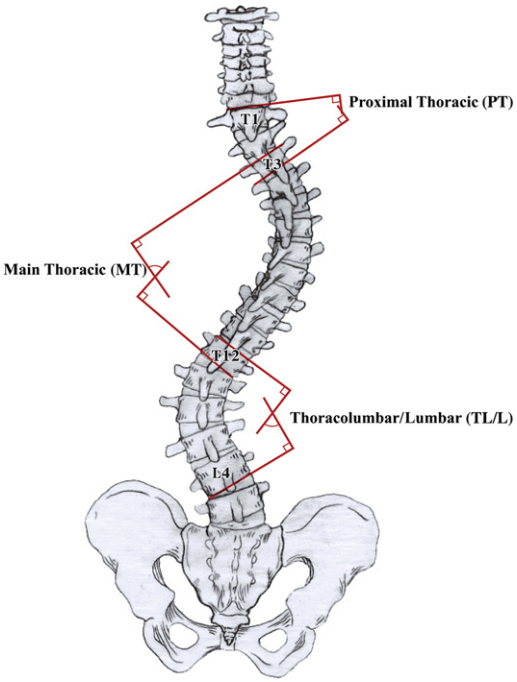


Fig. 3. Schematic of the coronal Cobb angle measurement technique of the PT, MT, and TL-L curves. Lines are drawn from the superior end plate of the cephalad end vertebra (EV) and the inferior end plate of the caudad EV. The angle subtended by the intersection of the lines drawn orthogonal to these is the Cobb angle. Curve EVs are, by definition, those vertebrae at the end of a curve that produce the curve of the greatest magnitude. (*From* O'Brien MF, Kuklo TR, Blanke KM, et al. Spinal deformity radiographic measurement manual. Memphis (TN): Medtronic Sofamor Danek USA; 2004. p. 49; with permission.)

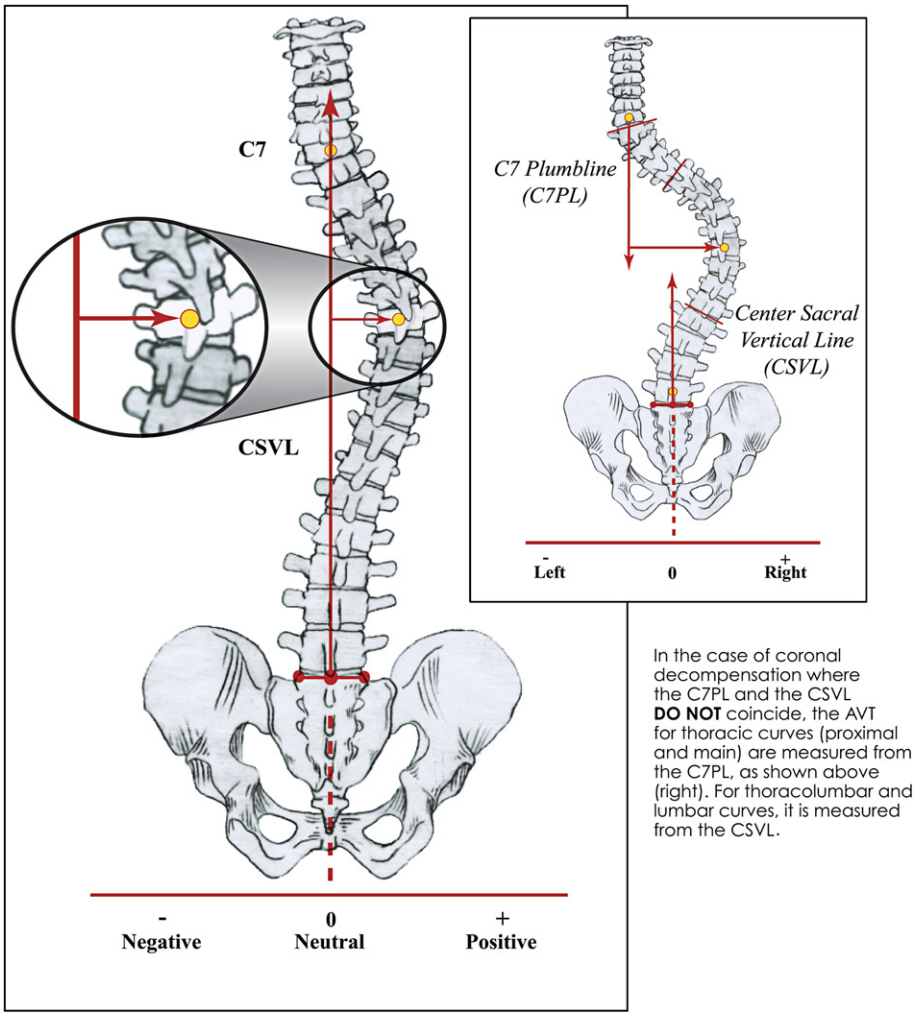


Fig. 4. Schematic of the AVT measurement technique. The horizontal distance from the centroid of the apical vertebrae is determined from the C7 plumb line (C7PL). (*From* O'Brien MF, Kuklo TR, Blanke KM, et al. Spinal deformity radiographic measurement manual. Memphis (TN): Medtronic Sofamor Danek USA; 2004. p. 51; with permission.)

The importance of this validation of standard measurements is for reliability in serial evaluations, communication, and comparison. For the AP radiograph, each of these measures proved to have good or excellent reliability, except for (1) the angulation of the disc below the LIV, (2) the apical Nash-Moe rotation, and (3) Risser grading of the iliac crest apophysis, all of which were only found to have fair reliability. For the lateral radiograph, only the sagittal T2-T5 measurement was found to have poor reliability [11]. This is mostly secondary to the soft tissue and bony crowding of the shoulders.

## Classification and analysis

A well-established or reliable classification of adult scoliosis is not currently available. Nonetheless, various authors have proposed classification schemes [12,13]. To date, it is the authors' preference to use the Lenke [14] classification as established for adolescent idiopathic scoliosis (AIS) as a starting point in the evaluation of adult scoliosis. This provides a comprehensive systematic evaluation of regional curves. Nonetheless, this should not be misconstrued as definitive for adult deformity.

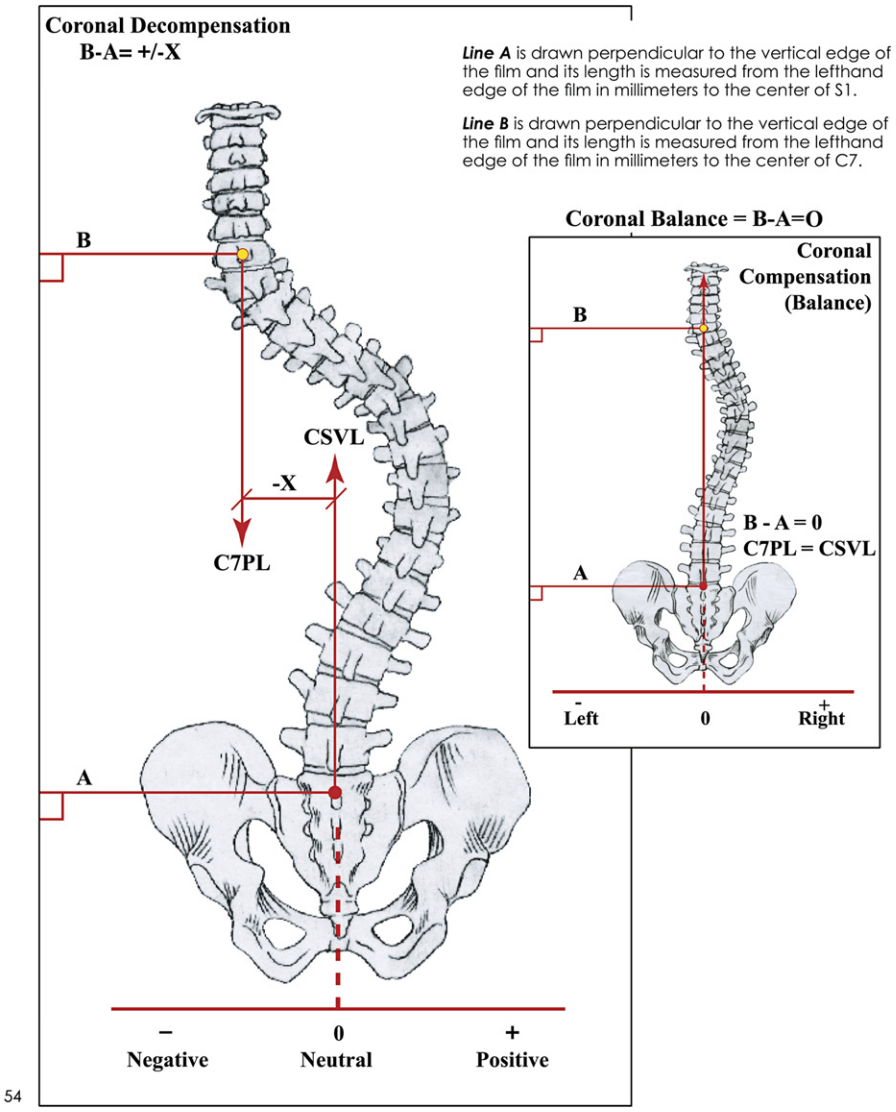


Fig. 5. Coronal balance is determined by the horizontal distance from the C7 plumb line (C7PL) to the center sacral vertical line (CSVL), with a shift of the C7PL to the right of the CSVL being positive and a shift to the left being negative. (*From* O'Brien MF, Kuklo TR, Blanke KM, et al. Spinal deformity radiographic measurement manual. Memphis (TN): Medtronic Sofamor Danek USA; 2004. p. 54; with permission.)

Using the Lenke [14] classification for AIS, a structural curve is defined by a Cobb angle of 25° or greater on side-bending radiographs. Just as importantly, the overall flexibility is important to note because this gives an indication of the expected curve correction without using advanced surgical techniques, such as osteotomies. In addition to the structural characteristics of the various curves, the radiographs should be evaluated for overall coronal and sagittal balance with particular attention to the center sacral vertical line (CSVL) and C7 plumb line (C7PL), shoulder height, AVT of the thoracic and lumbar curves, curve flexibility, and relative curve magnitudes [15]. Different from AIS, evaluation of the adult patient with deformity should also include

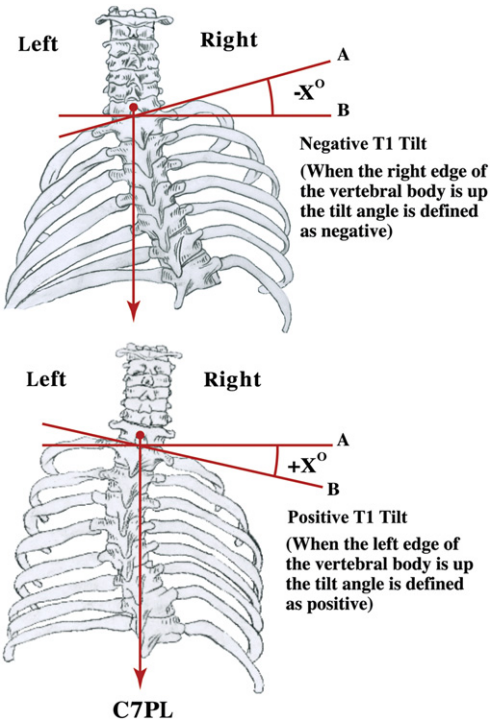


Fig. 6. T1 tilt is the angle formed between a line drawn along the superior end plate of T1 and a horizontal line drawn at the same level. T1 tilting to the left is negative, and T1 tilting to the right is positive. C7PL, C7 plumb line. (*From* O'Brien MF, Kuklo TR, Blanke KM, et al. Spinal deformity radiographic measurement manual. Memphis (TN): Medtronic Sofamor Danek USA; 2004. p. 55; with permission.)

a critical analysis of degenerative changes and rotatory or lateral listhesis, which inherently makes selection of fusion levels more difficult. In additional, a clinical assessment of sagittal and coronal balance, curve flexibility, and location of pain (if present) is important and should be analyzed with consideration of degenerative levels [16]. In the adult population, foraminal stenosis and central stenosis are quite common and are important considerations in the surgical plan. MRI or CT-myelography is used to evaluate these conditions. When choosing fusion levels, one should avoid ending a fusion adjacent to a severely degenerated disc, especially if there is a fixed tilt or subluxation present on the standing radiographs [17].

Shoulder balance is best determined with close clinical observation; however, the clavicle angle is a useful adjunct that has been shown to correlate the clinical and radiographic evaluations [18,19]. This is particularly useful, because the traditional teaching of evaluating the T1 tilt for PT curve characteristics and shoulder balance has not been shown to be reliable [20].

Analysis of the end vertebra (EV), neutral vertebra (NV), and stable vertebra (SV) is also of critical importance when selecting distal fusion levels in AIS. This also has clinical significance for adult deformity. For instance, the SV should ideally be selected as the LIV for most adult deformity, because compensation of the spine after instrumentation is minimal. This is frequently L5 but can also be L4. A more common scenario in the aging population, however, remains choosing between L5 and S1/ilium. When not accomplished, "adding on" or "falling off" is frequently encountered and a revision procedure is generally required. The reliability of selecting these levels is variable, with intraobserver reliability determined to be good to excellent for EV selection, good for NV selection, and good to excellent for SV selection [21]. As well, a trend toward greater intraobserver reliability was noted with increasing levels of observer experience. Interobserver reliability, however, was poor, with complete interobserver agreement between three observers being only 48.7% for EV selection, 41.7% for NV selection, and 51.0% for SV selection [21].

## Discussion

Proper management of the patient with spinal deformity requires a thorough understanding of coronal and sagittal balance, curve evaluation, and instrumentation techniques. Commensurate with this is a complete understanding of radiographic parameters and quality radiographic techniques. Reproducibility is paramount to optimal care and evaluation. Consequently, process measures play a central role in our evaluation.

This article has attempted to review the standard radiographic methodology for obtaining consistent reproducible radiographs as well as providing a brief review of radiographic measurement reliability and validity. In addition, a quick overview of regional curve flexibility, or lack thereof, has been included. It is not meant to be a summary of the Lenke classification or selection of fusion levels but rather a primer for standard radiographic techniques and measurements.

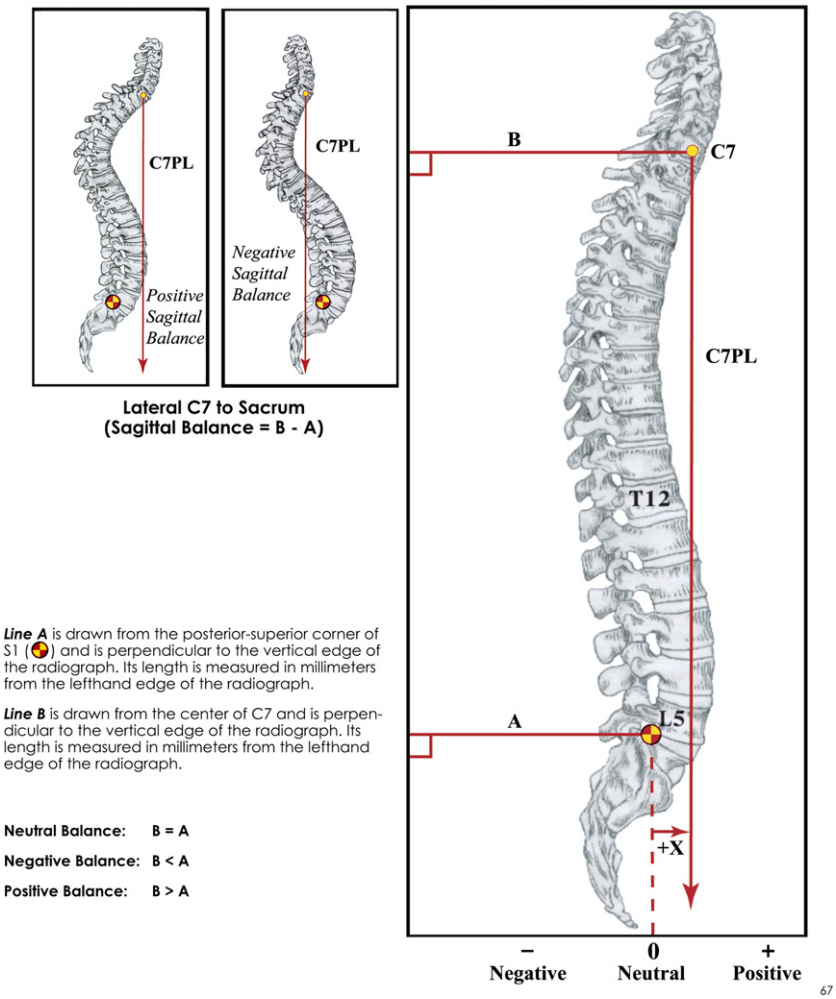


Fig. 7. Sagittal balance as depicted by the C7 plumb line (C7PL). (*From* O'Brien MF, Kuklo TR, Blanke KM, et al. Spinal deformity radiographic measurement manual. Memphis (TN): Medtronic Sofamor Danek USA; 2004. p. 67; with permission.)

Further study is needed to determine any correlation between these process measures and various outcomes measures.

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