表 1（つづき）

名　称	英語版：Zurich claudication questionnaire	日本語版：チューリヒ跛行質問票(ZCQ)
前　書	In the last month, on a typical day：	最近 1ヵ月における平均的な 1 日について考えて下さい
質問文	How far have you been able to walk?	どのくらいの距離を歩くことができましたか？
回答肢	more than 2 miles	3 km 以上
	more than 2 blocks, but less than 2 miles	数百 m 以上，3 km 未満
	more than 50 feet, but less than 2 blocks	15 m 以上，数百 m 未満
	less than 50 feet	15 m 未満
質問文	Have you taken walks outdoors or in malls for pleasure?	戸外やショッピングセンター内を散歩したりしましたか？
回答肢	yes, comfortably	はい，痛みがなく楽に歩けた
	yes, but sometimes with pain	はい，しかしときどき痛みがあった
	yes, but always with pain	はい，しかし痛みが常にあった
	no	いいえ，歩けなかった
質問文	Have you been shopping for groceries or other items?	食料品・日用品やその他の物などの買い物に出かけましたか？
回答肢	yes, comfortably	はい，痛みがなく楽に出かけられた
	yes, but sometimes with pain	はい，しかしときどき痛みがあった
	yes, but always with pain	はい，しかし痛みが常にあった
	no	いいえ，出かけられなかった
質問文	Have you walked around the different rooms in your house or apartment?	家の中をほかの部屋に行ったりして歩きましたか？
回答肢	yes, comfortably	はい，痛みがなく楽に歩けた
	yes, but sometimes with pain	はい，しかしときどき痛みがあった
	yes, but always with pain	はい，しかし痛みが常にあった
	no	いいえ，歩けなかった
質問文	Have you walked from your bedroom to the bathroom?	寝室からトイレまで歩きましたか？
回答肢	yes, comfortably	はい，痛みがなく楽に歩けた
	yes, but sometimes with pain	はい，しかしときどき痛みがあった
	yes, but always with pain	はい，しかし痛みが常にあった
	no	いいえ，歩けなかった

名　称	英語版：Zurich claudication questionnaire	日本語版：チューリヒ跛行質問票(ZCQ)
前　書	How satisfied are you with：	以下の事柄について，どの程度満足していますか？
質問文	The overall result of your back operation?	全体的に考えて，腰の手術結果に満足していますか？
回答肢	very satisfied	非常に満足
	somewhat satisfied	やや満足
	somewhat dissatisfied	やや不満足
	very dissatisfied	非常に不満足
質問文	Relief of pain following the operation?	手術後，痛みの軽減に満足していますか？
回答肢	very satisfied	非常に満足
	somewhat satisfied	やや満足
	somewhat dissatisfied	やや不満足
	very dissatisfied	非常に不満足
質問文	Your ability to walk following the operation?	手術後，歩行能力に満足していますか？
回答肢	very satisfied	非常に満足
	somewhat satisfied	やや満足
	somewhat dissatisfied	やや不満足
	very dissatisfied	非常に不満足
質問文	Your ability to do housework, yard work, or job following the operation?	手術後，家事や庭仕事，仕事の出来具合に満足していますか？
回答肢	very satisfied	非常に満足
	somewhat satisfied	やや満足
	somewhat dissatisfied	やや不満足
	very dissatisfied	非常に不満足
質問文	Your strength in the thighs, legs, and feet?	太ももや脚（あし），足部の力強さに満足していますか？
回答肢	very satisfied	非常に満足
	somewhat satisfied	やや満足
	somewhat dissatisfied	やや不満足
	very dissatisfied	非常に不満足
質問文	Your balance, or steadiness on your feet?	バランス，または立ったときの安定感に満足していますか？
回答肢	very satisfied	非常に満足
	somewhat satisfied	やや満足
	somewhat dissatisfied	やや不満足
	very dissatisfied	非常に不満足

第 3 案に表現および語句の修正を実施し，日本語翻訳最終版とした．

結　　果

原作版と日本語版の比較を表 1 に示す．

1．順翻訳および逆翻訳（日本語翻訳第 3 案の作成）

順翻訳および逆翻訳を実施し，日本語翻訳第 3 案を作成するまでに検討した主な内容を下記に記した．

“In the last month, how would you describe：” は「：」に続く質問項目が目的語になっており，英語特有の構文である．日本語としての理解しやすさを考慮し依頼形の表現にした．質問票全体をとおして回答肢間の間隔（程度）が不均一にならないように考慮した．

“The pain in your back or buttocks?” に「どうでしたか」という語句を加え，日本語として理解しやすくした．

“Numbness or tingling in your legs or feet?” の “tingle” の意味は “if a part of your body tingles, you

チューリヒ跛行質問票

最近１ヶ月の状態について回答して下さい。

痛みは平均してどの程度でしたか？（腰やおしりの痛み、またそこから脚にまで及ぶ痛みを含みます。）

痛みは全く なかった □	弱い痛み であった□	中程度の痛み であった□	強い痛み であった□	非常に強い痛み であった□

どの位の頻度で腰、おしり、あるいは脚の痛みがありましたか？

- １週間に１回未満 □
- １週間に少なくとも１回 □
- 少なくとも１日１回 □
- １日の大半 □
- 四六時中痛みがある □

腰あるいは おしりの痛みはどうでしたか？

痛みは全く なかった □	弱い痛み であった□	中程度の痛み であった□	強い痛み であった□	非常に強い痛み であった□

脚や足部の痛みはどうでしたか？

痛みは全く なかった □	弱い痛み であった□	中程度の痛み であった□	強い痛み であった□	非常に強い痛み であった□

脚や足部のしびれや うずきはどうでしたか？

しびれやうずき は全くなかった□	弱いしびれや うずきであった□	中程度のしびれや うずきであった □	強いしびれや うずきであった□	非常に強いしびれや うずきであった □

脚や足部の衰え具合はどうでしたか？

衰えは全く なかった □	軽い衰え であった □	中程度の衰え であった □	激しい衰え であった □	非常に激しい 衰えであった□

バランス（安定感）に問題はありましたか?

- いいえ、バランスをとることに全く問題はなかった □
- はい、バランスを崩したり足元がしっかりしていなかったりすると、ときどき感じた □
- はい、バランスを崩したり足元がしっかりしていなかったりすると、しばしば感じた □

図 2. チューリヒ跛行質問票

feel a slight stinging feeling, especially on your skin”（英英）や「人・体がぞくぞく，うずうずする」（英和）と記載されている．また，“stinging” の意味として「刺すような」（英英）と記載されており，slight stinging feeling の意味とも合致する「うずき」と翻訳した．

“Weakness in your legs or feet?” の “weakness” は当初「衰弱」と翻訳した．しかし，「衰弱」とは「衰え弱ること」（『広辞苑』）であり，“weakness：state of being physically weak”（英英）であることをふまえると，「衰え」が適切であると考え採用した．

Physical function を問う質問群に対する回答肢 “no” には，“could not walk” の意味が含まれているため，「いいえ，歩けなかった」と翻訳した．

“mile” および “block” は「km（キロメートル）」お

最近１ヶ月における平均的な１日について考えて下さい。

どの位の距離を歩くことができましたか？

- 3 キロメートル以上 ☐
- 数百メートル以上、3 キロ未満 ☐
- 15 メートル以上、数百メートル未満 ☐
- 15 メートル未満 ☐

戸外やショッピングセンター内を散歩したりしましたか？

- はい、痛みがなく楽に歩けた ☐
- はい、しかし時々痛みがあった ☐
- はい、しかし痛みが常にあった ☐
- いいえ、歩けなかった ☐

食料品・日用品やその他の物などの買い物に出かけましたか？

- はい、痛みがなく楽に出かけられた ☐
- はい、しかし時々痛みがあった ☐
- はい、しかし痛みが常にあった ☐
- いいえ、出かけられなかった ☐

家の中を他の部屋に行ったりして歩きましたか？

- はい、痛みがなく楽に歩けた ☐
- はい、しかし時々痛みがあった ☐
- はい、しかし痛みが常にあった ☐
- いいえ、歩けなかった ☐

寝室からトイレまで歩きましたか？

- はい、痛みがなく楽に歩けた ☐
- はい、しかし時々痛みがあった ☐
- はい、しかし痛みが常にあった ☐
- いいえ、歩けなかった ☐

以下のことがらについて、どの程度満足していますか？

全体的に考えて、腰の手術結果に満足していますか？

- 非常に満足 ☐
- やや満足 ☐
- やや不満足 ☐
- 非常に不満足 ☐

手術後、痛みの軽減に満足していますか？

- 非常に満足 ☐
- やや満足 ☐
- やや不満足 ☐
- 非常に不満足 ☐

手術後、歩行能力に満足していますか？

- 非常に満足 ☐
- やや満足 ☐
- やや不満足 ☐
- 非常に不満足 ☐

手術後、家事や庭仕事、仕事の出来具合に満足していますか？

- 非常に満足 ☐
- やや満足 ☐
- やや不満足 ☐
- 非常に不満足 ☐

太ももや脚(あし)、足部の力強さに満足していますか？

- 非常に満足 ☐
- やや満足 ☐
- やや不満足 ☐
- 非常に不満足 ☐

バランス、または立った時の安定感に満足していますか？

- 非常に満足 ☐
- やや満足 ☐
- やや不満足 ☐
- 非常に不満足 ☐

図 2（つづき）

よび「m（メートル）」に換算して翻訳することとし，原作者の了承を得た．

原作版で "leg"，"feet"，"typical"，"strength" の各語句については翻訳案が複数あり，患者調査の結果をふまえて決定することとした．

2．患者調査

LCS 患者 5（男性 3，女性 2）例を対象に個別面談方式による調査を実施した．参加者の平均年齢は，72.4（66～79）歳であった．平均回答時間は 13.4（9～18）分であった．調査の結果をふまえ，個々の質問項目について検討した結果を以下に記す．

ほとんどの参加者がこの質問票の質問内容および回答肢の意味について理解していた．2 名の参加者より「痛いのは背中とおしりではなく腰である」との意見があっ

記入時の注意事項

※ あまり考えすぎず，感じたとおりにお答え下さい

※ 質問票にある「脚(あし)」と「足部」とは下図の部位を指します

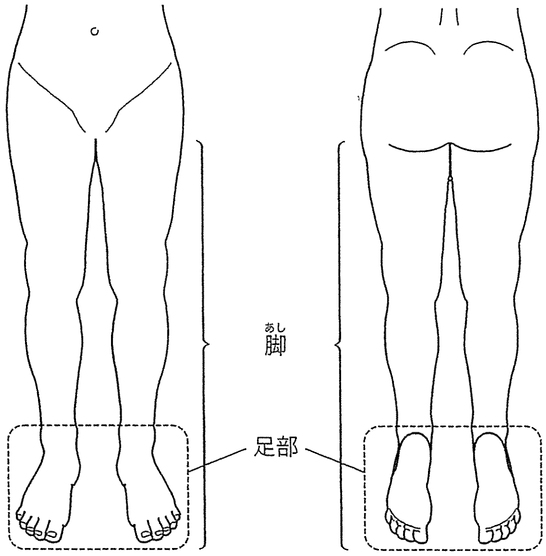

図 3．チューリヒ跛行質問票（ZCQ）

た．「背中」と翻訳した英語“back”について，臨床医より「日本語の『腰痛』に該当する英語は“low back pain”であるが，西欧では“back pain”も同義として使用する場合もある」との意見があった．検討した結果，“back”を「腰」に修正した．

翻訳第 3 案作成時に“leg or feet”の訳として「足や足先」および臨床で通常使われている「脚や足部」ではどちらが理解しやすいか調査の結果をふまえて決定することにした．調査の結果，「足」と「脚」では言葉が示す部位の理解が参加者間で異なっていた．また，3 名の参加者より「『足部』はどこを示すかわからない」との意見があった．検討した結果，「記入時の注意事項（図 3 参照）」を別に作成し，“leg”および“feet”が示す部位を図示した．なお，質問票の“leg or feet”の訳として「脚(あし)や足部」に決定した．3 名の参加者より「『うずき』はわかりづらく，回答しづらい」との意見があった．検討の結果，「しびれ」が理解できれば質問に回答可能であるため，変更は行わず注釈もつけないこととした．

翻訳第 3 案作成時に，「典型的な 1 日」と「平均的な 1 日」のどちらが理解しやすいか調査の結果をふまえて決定することにした．調査の結果，3 名より「『平均的な 1 日』のほうがわかりやすい」との意見があったため，「平均的な 1 日」に決定した．回答肢「はい，痛みがなく楽に買い物ができた」について，回答に対応する質問の意図として「買い物ができた」より「出かけられた」に重点がおかれているため，「はい，痛みがなく楽に出かけられた」に修正し，最終的な翻訳として採用した．すべての参加者より「『歩き回る』は広い家の場合に使用する表現であり自分の家には不適切である」との意見があった．検討の結果，日本の住居環境に適した言葉とするため．「歩き回る」を「歩き」に修正した．また，「家の中でほかの部屋に行ったりして歩きましたか？」より「家の中をほかの部屋に行ったりして歩きましたか？」のほうが日本語として自然な表現であると判断し，修正した．3 名の一般成人男女を対象に修正案についての調査を実施したところ，質問の意図を正しく理解していたため，上記の修正案を最終的な翻訳として採用した．

“bathroom”には「浴室」だけでなく，「トイレ」も備わっている場合が多い（英和）．日本では浴室とトイレは別々の部屋にある場合が多いため，どちらかに限定する必要があると考えた．最近 1ヵ月の 1 日（physical function）についての質問群は，質問がすすむに従い，日常生活の活動範囲が狭くなるように構成されている．この質問は日常生活の活動範囲がもっとも狭い場合に該当する．日常生活では，一般的に浴室（入浴）よりトイレ（排泄）の必要性が高いことを考慮すると，“bathroom”を「トイレ」とするほうが適切であると判断した．また，臨床医からも同様の意見があったため，検討の結果「浴室」を「トイレ」に修正した．3 名の一般成人男女を対象に修正案についての調査を実施したところ，質問の意図を正しく理解していたため，上記の修正案を最終的な翻訳として採用した．

翻訳第 3 案作成時に，「強さ」と「力強さ」のどちらが理解しやすいか調査の結果をふまえて決定することにした．調査の結果，4 名から「『太ももや足，足先の強さに満足していますか？』のほうがわかりやすい」との意見があった．しかし臨床医からは，「筋力の強さを明示するためには，『強さ』より『力強さ』のほうが適している」との意見があった．検討の結果，臨床医の経験から得られた意見に従い，「力強さ」に決定した．調査の結果からも質問の意図自体は力強さでも正しく理解されていたため，上記の最終案で特に問題はないものと考えた．

3．日本語版の作成

患者調査の結果をふまえ，上記の修正を加え，その内容について原作者の同意を得た．一連の手順に従って原作版を翻訳し，言語的妥当性の担保された「日本語版ZCQ」を確定した（図2，3）．

考　　察

ZCQはLCSに疾患特異的な評価尺度であり，英語版以外に複数の言語で言語的妥当性が確認された翻訳版が作成されている．現時点においても重症度判定や治療効果判定として幅広く使われているが，2007年の北米脊椎学会のガイドラインに推奨されたことにより，今後さらに世界的に広く使用されるようになると予想される．本研究では，ZCQを日本でも使用できるようにZCQの日本語版を作成した．

他言語の質問票についての翻訳版の作成にあたっては，文化的な背景および言語の相違を慎重に考慮する必要がある．今回の研究では，質問票の翻訳版の言語的妥当性を担保するために使用される標準的手法を用いて日本語版を作成した．翻訳者・臨床医および原作者が検討を複数回実施し，患者調査により患者の意見をとり入れたうえでさらに検討を行うことで，言語的な精度を高めてゆくことができた．これらの過程を経て，原作版と同じ概念を有し，言語的に妥当性のある翻訳がなされた日本語版ZCQが完成した．今後必要に応じて日本語の文章表現について検討を実施し，質問票としての精度をさらに高めてゆくことが重要である．

また，今後は信頼性や妥当性などの計量心理学的な検討を実施する必要があると考えており，筆者らは約100名のLCS患者を対象に計量心理学的検討をすすめている．

ま と め

質問票の翻訳版の言語的妥当性を担保するために使用される標準的手法を用いて，言語的妥当性の担保された「日本語版ZCQ」を作成した．

文　献

1) 長総義弘：疫学．NEW MOOK 整外 **9**：60-65，2001
2) 紺野愼一，林野泰明，福原俊一ほか：腰部脊柱管狭窄症の診断サポートツール．臨整外 **41**：859-864，2006
3) 松平　浩，岸本淳司，原　慶宏ほか：腰部脊柱管狭窄症の実態—症状と抑うつおよび健康関連QOLの関係．日腰痛研会誌 **13**：192-196，2007
4) Stucki GE, Daltroy LA, Liang MA et al：Measurement properties of a self-administered outcome measure in lumbar spinal stenosis. Spine **21**：796-803, 1996
5) Thornes EL, Grotle MA：Cross-cultural adaptation of the Norwegian version of the spinal stenosis measure. Eur Spine J **17**：456-462, 2008
6) NASS Clinical Guidelines Committee：B. Outcome measures for medical/interventional and surgical treatment. Clinical Guidelines for Multidisciplinary Spine Care；Diagnosis and Treatment of Degenerative Lumbar Spinal Stenosis, ed by North American Spine Society, North American Spine Society, Burr Ridge, p44-45, 2007
7) Guillemin F, Bombardier C, Beaton D：Cross-cultural adaptation of health-related quality of life measures, literature review and proposed guidelines. J Clin Epidemiol **46**：1417-1432, 1993
8) 鈴鴨よしみ，熊野宏昭：計量心理学．臨床のためのQOLハンドブック，池上直己，福原俊一，下妻晃二郎ほか（編），医学書院，東京，p8-13，2001

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ORIGINAL ARTICLE

Predictors of residual symptoms in lower extremities after decompression surgery on lumbar spinal stenosis

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Abstract Leg pain/numbness and gait disturbance, two major symptoms in the lower extremities of lumbar spinal stenosis (LSS), are generally expected to be alleviated by decompression surgery. However, the paucity of information available to patients before surgery about specific predictors has resulted in some of them being dissatisfied with the surgical outcome when the major symptoms remain after the procedure. This prospective, observational study sought to identify the predictors of the outcome of a decompression surgery: modified fenestration with restorative spinoplasty. Of 109 consecutive LSS patients who underwent the decompression surgery, 89 (56 males and 33 females) completed the 2 year follow-up. Both leg pain/numbness and gait disturbance determined by the Japanese Orthopedic Association scoring system were significantly improved at 2 years after surgery compared to those preoperative, regardless of potential predictors including gender, preoperative presence of resting numbness in the leg, drop foot, cauda equina syndrome, degenerative spinal deformity or myelographic filling defect, or the number of decompressed levels. However, 27 (30.3%) and 13 (14.6%) patients showed residual leg pain/numbness and gait disturbance, respectively. Among the variables examined, the preoperative resting numbness was associated with residual leg pain/numbness and gait disturbance, and the preoperative drop foot was associated with residual gait disturbance, which was confirmed by logistic regression analysis after adjustment for age and gender. This is the first study to identify specific predictors for these two remaining major symptoms of LSS after decompression surgery, and consideration could be given to including this in the informed consent.

Keywords Lumbar spinal stenosis · Decompression surgery · Outcome · Predictor

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Introduction

Lumbar spinal stenosis (LSS) is a degenerative disorder causing neurological symptoms in the lower extremities such as leg pain/numbness and gait disturbance, both of which dramatically deteriorate the patients' quality of life [3, 4, 17]. With elderly populations growing worldwide, degenerative LSS has become the most frequent indication for spine surgery [12]. The most common surgery is decompression of the lumbar spine, which is performed mainly to reduce the above symptoms in the lower extremities. In fact, a prospective study revealed that the surgery generally resulted in a more preferable greater outcome than non-surgical treatments in the LSS patients [20]. However, about 20–40% of patients have been reported to be dissatisfied with the result due to residual symptoms [1, 8, 9]. To avoid the discrepancy between a patient's expectations and actual surgical outcome, a surgeon should preoperatively inform the patient in detail of the possible post-surgery outcome of the major symptoms such as leg pain/numbness and gait disturbance.

There have been several reports on the factors that could predict the outcome of LSS surgeries [7–9, 15, 19]; however, some of the surgeries included arthrodesis in addition to decompression. Furthermore, the outcomes were evaluated using several validated measures, so that they covered a broad range including low back pain, psychological status, patients' satisfaction, quality of life, etc. other than symptoms in the lower extremities. Hence, the predictors identified are rather ambiguous such as the presence of other comorbidities, patient's assessment of his/her health, subclinical vascular factors and illness behavior. Since little has been known about the specific predictors of outcomes in the lower extremities after decompression surgery, this study sought to identify the factors associated with two major symptoms in the lower extremities of LSS patients: leg pain/numbness and gait disturbance, after a minimally invasive decompression surgery.

Materials and methods

Patients

Consecutive patients, who were blinded to the study, were entered into this prospective observational study from January 2000 through December 2002. Symptoms of leg pain/numbness and/or gait disturbance in LSS patients, which did not respond to conservative therapies for more than 3 months, were considered to be indications for the decompression surgery [10]. The LSS was confirmed by plain radiographs, magnetic resonance imaging and myelography followed by contrast-enhanced computed tomography scan. The patients with severe spinal deformity (spondylolisthesis with Meyerding grades ≥II or lumbar scoliosis with Cobb angle >20 degrees), spondylolysis, post-traumatic stenosis or re-stenosis after prior decompression surgery were excluded, because they were indicated for an additional arthrodesis surgery. A total of 109 patients who met the criteria underwent our original decompression surgery called modified fenestration with restorative spinoplasty [11]. They were allowed to sit up and walk on the 1st or 2nd postoperative day with a soft lumbar support. Examinations were performed preoperatively and at 2 years after surgery. The study was conducted with the approval of the institutional review board (IRB) and all participants (blinded) provided written informed consent.

Data elements

The severity of leg pain/numbness or gait disturbance was evaluated as four grades according to the Japanese Orthopedic Association (JOA) scoring system [5]: 0 (none), 1 (occasionally mild), 2 (always present or sometimes severe) and 3 (always severe) for leg pain/numbness; and 0 (none), 1 (able to walk >500 m with pain/numbness/weakness), 2 (unable to walk 500 m due to pain/numbness/weakness) and 3 (unable to walk 100 m due to pain/numbness/weakness) for gait disturbance. The presence of a residual symptom was defined as a JOA score of 0 or 1 at 2 years after surgery, regardless of the preoperative score. In addition, a score of 2 after 2 years and of 2 or 3 preoperatively were also regarded as the presence of a residual symptom. Potential predictors of outcome included age, gender, preoperative presence of resting numbness in the leg, drop foot [manual muscle test (MMT) score below 3 out of 5 in the tibialis anterior and/or peroneal muscle], cauda equina syndrome (urinary retention, perineal anesthesia or symptoms in bilateral lower extremities), degenerative spinal deformity (spondylolisthesis with more than 5% anterior slippage by the Taillard method [16] and/or lumbar scoliosis with more than 10 degrees of Cobb angle) on plain radiographs, a complete filling defect on myelography in the standing position and the number of decompressed levels. Radiographic findings were independently evaluated by three spine surgeons and were determined with the agreement of at least two of them.

Analyses

Statistical analyses were performed using the SPSS 16.0J for Windows. A P value of <0.05 was considered to be statistically significant and all reported P values were two sided. Paired t test was used to examine the difference between the preoperative and postoperative JOA scores. Association of age, gender, preoperative presence of the above findings or the number of decompressed levels with residual leg pain/numbness or gait disturbance was evaluated by chi-square test in the stratified subgroups. Logistic regression analysis was performed to estimate odds ratio (OR) and the associated 95% confidence interval (CI) after adjustment for age and gender.

Results

Comparison of preoperative and postoperative scores

Of the 109 patients enrolled, 101 (93%) could be followed postoperatively for 2 years. The reasons for the eight dropouts were two deaths from lung cancer and heart failure, three moved to distant areas and three lost contact. Twelve other patients who showed symptoms in the lower extremities due to cerebral infarction, myelopathy or dementia during the postoperative follow-up period were excluded. Symptoms in the lower extremities of the remaining 89 patients (56 males and 33 females; mean ± SD, 66.3 ± 11.2 years) were surveyed 2 years after surgery. There was no complication in the surgical procedure except for slight dural tears in four patients, which were repaired without additional treatment. During the follow-up period, a superficial infection, a pseudomembranous enteritis, a disc herniation at the operated level and a compression vertebral fracture occurred, all of which were cured with conservative therapies. None of the patients underwent spinal re-operation because of progression of stenosis or instability.

The background data of the 89 patients are shown in Table 1. Comparison of preoperative and postoperative JOA scores on symptoms in the lower extremities of all the patients revealed that both leg pain/numbness (1.0–2.0) and gait disturbance (0.7–2.4) were significantly improved by surgery (Table 1). The stratified comparisons by gender, preoperative presence of the above findings and the number of decompressed levels showed that the JOA scores of both symptoms were significantly improved by the surgery in all subgroups. However, the subgroup with preoperative drop foot showed somewhat less improvement in both leg pain/numbness ($P = 0.009$) and gait disturbance ($P = 0.007$) than other subgroups ($P < 0.0001$).

Predictors of the residual symptoms in lower extremities

According to the definition of residual symptoms as above, 27 (30.3%) and 13 (14.6%) patients showed residual leg pain/numbness and gait disturbance, respectively (Table 2). To identify the predictors of residual symptoms in the lower extremities, we compared the number (percentage) of patients with and without residual symptoms in the stratified subgroup according to the variables. Among the variables, preoperative resting numbness was positively associated with both residual leg pain/numbness ($P = 0.03$) and residual gait disturbance ($P = 0.02$). Furthermore, preoperative drop foot was more strongly associated with residual gait disturbance ($P = 0.0002$), although not with residual leg pain/numbness. Age, gender, preoperative presence of cauda equina syndrome, degenerative spinal deformity, myelographic complete filling defect or the number of decompressed levels was not associated with either of the residual symptoms in the lower extremities.

To further identify the principal predictors, we further performed logistic regression analysis after adjustment for age and gender to estimate OR and 95% CI. We confirmed the significant association of resting numbness with residual leg pain/numbness and gait disturbance, as well as the significant association of drop foot with residual gait disturbance (Table 3).

Table 1 Comparison of preoperative and postoperative JOA scores on symptoms in lower extremities

		n	Leg pain/numbness				Gait disturbance			
			Preop. (SD)	Postop. (SD)	Change (SD)	*P* value	Preop. (SD)	Postop. (SD)	Change (SD)	*P* value
All		89	1.0 (0.5)	2.0 (0.8)	10 (0.8)	<0.0001	0.7 (0.8)	2.4 (0.8)	1.8 (1.0)	<0.0001
Gender	Male	56	1.0 (0.6)	2.1 (0.8)	1.1 (0.8)	<0.0001	0.7 (0.8)	2.4 (0.8)	1.7 (0.9)	<0.0001
	Female	33	0.9 (0.4)	1.8 (0.8)	0.9 (0.8)	<0.0001	0.6 (0.8)	2.4 (0.8)	1.8 (1.0)	<0.0001
Resting numbness	(+)	40	0.9 (0.5)	1.4 (0.7)	0.6 (0.7)	<0.0001	0.6 (0.7)	2.2 (0.9)	1.6 (1.0)	<0.0001
	(−)	49	1.1 (0.6)	2.5 (0.5)	1.4 (0.6)	<0.0001	0.8 (0.8)	2.7 (0.6)	1.9 (0.9)	<0.0001
Drop foot	(+)	9	0.9 (0.8)	1.9 (0.6)	1.0 (0.9)	0.009	0.6 (0.9)	1.9 (1.2)	1.3 (1.1)	0.007
	(−)	80	0.9 (0.5)	2.0 (0.8)	1.0 (0.8)	<0.0001	0.7 (0.8)	2.5 (0.7)	1.8 (0.9)	<0.0001
Cauda equina syndrome	(+)	66	0.9 (0.5)	1.9 (2.2)	1.0 (0.8)	<0.0001	0.6 (0.7)	2.4 (0.8)	1.8 (0.9)	<0.0001
	(−)	23	1.0 (0.7)	2.2 (0.9)	1.0 (0.8)	<0.0001	0.9 (0.9)	2.4 (0.7)	1.5 (1.0)	<0.0001
Degenerative spinal deformity	(+)	47	1.0 (0.6)	2.0 (0.8)	1.0 (0.8)	<0.0001	0.7 (0.8)	2.4 (0.7)	1.7 (0.9)	<0.0001
	(−)	42	0.9 (0.4)	2.0 (0.9)	1.1 (0.9)	<0.0001	0.6 (0.7)	2.5 (1.0)	1.9 (1.0)	<0.0001
Complete filling defect	(+)	56	0.9 (0.6)	1.9 (0.8)	1.0 (0.8)	<0.0001	0.7 (0.8)	2.4 (0.8)	1.7 (1.0)	<0.0001
	(−)	33	1.0 (0.5)	2.2 (0.9)	1.2 (0.7)	<0.0001	0.7 (0.8)	2.5 (0.8)	1.8 (0.9)	<0.0001
Number of decompressed levels	1	50	1.0 (0.5)	2.1 (0.7)	1.1 (0.7)	<0.0001	0.9 (0.8)	2.6 (0.6)	1.7 (0.8)	<0.0001
	≥2	39	0.9 (0.6)	1.9 (0.8)	0.9 (0.9)	<0.0001	0.4 (0.7)	2.2 (0.9)	1.8 (1.2)	<0.0001

P value was determined by the paired *t* test

Table 2 Number (percentage) of patients with and without residual symptoms in the lower extremities

		Leg pain/numbness			Gait disturbance		
		(+) $n = 27$	(–) $n = 62$	*P* value	(+) $n = 13$	(–) $n = 76$	*P* value
Mean age (years)		72.0	68.1	0.10	64.6	69.1	0.10
Gender	Male	17 (30.4)	39 (69.6)	0.26	10 (17.9)	46 (82.1)	0.26
	Female	10 (30.3)	23 (69.7)		3 (9.0)	30 (91.0)	
Resting numbness	(+)	26 (65.0)	14 (35.0)	0.03*	9 (22.5)	31 (77.5)	0.02*
	(–)	1 (2.0)	48 (98.0)		4 (8.2)	45 (91.8)	
Drop foot	(+)	4 (44.4)	5 (55.6)	0.33	5 (55.6)	4 (44.4)	0.0002*
	(–)	23 (28.8)	57 (61.2)		8 (10.0)	72 (90.0)	
Cauda equina syndrome	(+)	23 (34.8)	43 (65.2)	0.11	9 (13.6)	57 (86.4)	0.66
	(–)	4 (17.4)	19 (82.6)		4 (17.4)	19 (82.6)	
Degenerative spinal deformity	(+)	17 (36.2)	30 (63.8)	0.60	7 (14.9)	40 (55.1)	0.60
	(–)	10 (23.8)	32 (76.2)		6 (14.3)	36 (55.7)	
Complete filling defect	(+)	21 (37.5)	35 (62.5)	0.06	8 (14.3)	48 (85.7)	0.91
	(–)	6 (18.2)	27 (81.8)		5 (15.2)	28 (84.8)	
Number of decompressed levels	1	11 (22.0)	39 (78.0)	0.05	4 (8.0)	46 (92.0)	0.05
	≥2	16 (41.0)	23 (59.0)		9 (23.1)	30 (76.9)	

P value was determined by the chi-square test

Table 3 Logistic regression analyses for odds ratio (OR) and 95% confidence interval (CI) of the variables for residual symptoms in the lower extremities

	Leg pain/numbness		Gait disturbance	
	OR	(95% CI)	OR	(95% CI)
Resting numbness	85.6*	(15.9–1603.1)	4.5*	(1.2–23.2)
Drop foot	2.1	(0.5–9.0)	11.6*	(2.5–59.1)
Cauda equina syndrome	2.6	(0.09–4.1)	1.3	(0.006–2.5)
Degenerative spinal deformity	0.7	(0.1–4.9)	0.6	(0.1–2.2)
Complete filling defect	2.2	(0.9–2.4)	1.4	(0.004–2.3)
Number of decompressed levels	2.5	(1.0–2.7)	4.2	(0.06–9.8)

Data were calculated by logistic regression analysis after adjustment for age and gender, $*P < 0.01$

Discussion

This prospective observational study for the first time identified the specific predictors for the remaining major symptoms of LSS after decompression surgery: leg pain/numbness and gait disturbance. Preoperative resting numbness was found to be a predictor of both residual leg pain/numbness and gait disturbance, and preoperative drop foot was a predictor of residual gait disturbance. It would seem to be natural that preoperative resting numbness eventually leads to postoperative leg pain/numbness. In fact, 65.0% (26 of 40 patients) of patients with preoperative resting numbness still showed residual leg pain/numbness 2 years after the operation (Table 2). Numbness caused by LSS has been reported to be more difficult to alleviate by surgery than other neurological symptoms such as muscle weakness or pain [2, 6]. Also, it is not surprising that preoperative drop foot eventually leads to postoperative gait disturbance. More than half (55.6%; 5 of 9 patients) the patients with preoperative drop foot showed residual gait disturbance (Table 2). A previous study on the surgical outcome of LSS patients with drop foot revealed that especially those with a preoperative MMT score of 0 or 1 for ankle dorsiflexion exhibited poor alleviation of this disorder [1]. In the present study as well, there were three patients with an MMT score of 0 or 1, and all of them showed residual gait disturbance due to the unchanged drop foot (data not shown). Furthermore, comparison of preoperative and postoperative JOA scores revealed that the subgroup with preoperative drop foot showed less improvement of symptoms in the lower extremities than other subgroups (Table 1). Taken together, resting numbness and drop foot may be derived from less reversible neurological disorders, so that they are difficult to restore by decompression. The preoperative durations of these symptoms may influence the surgical outcomes, which we should examine as a next task. More interesting is that preoperative resting numbness, a sensory disorder, was identified as a predictor of residual gait disturbance, which is a motor disorder. Although the underlying mechanism remains unclear, we speculate a possible involvement of irreversible peripheral neural damage that is related to both resting numbness and gait disturbance.

In addition to resting numbness and drop foot, the number of decompressed levels also showed a trend toward positive association with residual leg pain/numbness and residual gait disturbance, although not statistically significant (Table 2, $P = 0.05$ in both symptoms; Table 3, OR = 2.5 and 4.2, respectively). Although the present comparison was performed between a single level of decompression and two or more levels of decompression, a comparison between one or two levels ($n = 80$) and three or more levels ($n = 9$) showed a significant association of the number of decompressed levels with residual leg pain/numbness ($P = 0.01$, OR = 7.5, 95% CI = 1.6–50.0), but not with residual gait disturbance ($P = 0.50$, OR = 1.3, 95% CI = 0.1–6.3) (data not shown in the tables). Indeed, there is greater possibility of multiple levels of decompression to cause surgical invasion, which may eventually result in the residual symptoms. Alternatively, independently of the surgery itself, residual symptoms may be derived from irreversible symptoms of the preoperative disorders, since the multi-level canal stenosis, which is an indication of multi-level decompression, may cause more damages to the nerve root, cauda equina and the blood circulation [13, 14, 18]. Hence, unlike preoperative symptoms such as resting numbness and drop foot, the number of decompressed levels may not be suitable for the predictor. In fact, previous reports on the relationship between the number of decompressed levels and the surgical outcome have been controversial, depending on the outcome measures including standardized instruments and self-reported satisfaction by patients [7, 9].

As the decompression surgery, the present study utilized our original technique called modified fenestration with restorative spinoplasty. Since this technique was developed to achieve good visibility of the spinal canal and safe decompression even in patients with narrow and steep facet joints, the ability to decompress the spinal canal and nerve roots is sufficient, similar to conventional laminectomy/foraminotomy techniques [11]. Hence, we believe that the present results obtained using this unique technique are applicable generally to typical decompression surgeries.

Although approximately 30 and 15% of patients were shown to have residual symptoms after the decompression surgery, respectively (Table 2), the present residual symptoms were defined according to our original criteria based on the JOA score and were not completely or directly linked with the dissatisfaction of the patients. Indeed, there are other factors such as back pain and psychological status to be considererd for the recommendation of the surgery. Furthermore, since the JOA scores of leg pain/numbness and gait disturbance were significantly improved after the surgery, regardless of the presence or absence of these predictors (Table 1), decompression surgery is definitely worth performing to decrease the severity of these symptoms. Hence, the present study suggests that it is desirable for this surgery to be performed before the onset of resting numbness or drop foot at least to prevent residual symptoms in the lower extremities. Even in the presence of these preoperative predictors, however, we encourage this surgery with sufficient informed consent, including the findings obtained from this study, to avoid misunderstanding or over-expectation of the patient with regard to the surgical outcome.

References

1. Aono H, Iwasaki M, Ohwada T et al (2007) Surgical outcome of drop foot caused by degenerative lumbar diseases. Spine 32:E262–E266
2. Babb A, Carlson WO (2006) Spinal stenosis. S D Med 59(3): 103–105
3. Berthelot JM, Bertrand VA, Rodet D et al (1997) Lumbar spinal stenosis: a review. Rev Rheum Engl Ed 64:315–325
4. Bolender NF, Schonstrom NSR, Spengler DM (1985) Role of computed tomography and myelography in the diagnosis of central spinal stenosis. J Bone Joint Surg 67A:240–246
5. Fujiwara A, Kobayashi N, Saiki K et al (2003) Association of the Japanese Orthopaedic Association score with the oswestry disability index, roland–morris disability questionnare, and short-Form 36. Spine 28:1601–1607
6. Goh KJ, Khalifa W, Anslow P et al (2004) The clinical syndrome associated with lumbar spinal stenosis. Eur Neurol 52:242–249
7. Gunzburg R, Keller TS, Szpalski M et al (2003) Clinical and psychofunctional measures of conservative decompression surgery for lumbar spinal stenosis: a prospective cohort study. Eur Spine J 12:197–204
8. Katz J, Stucki G, Lipson S et al (1999) Predictors of surgical outcome in degenerative lumbar spinal stenosis. Spine 24:2229–2233
9. Katz JN, Lipson SJ, Brick GW et al (1995) Clinical correlates of patient satisfaction after laminectomy for degenerative lumbar spinal stenosis. Spine 20:1155–1160
10. Matsudaira K, Yamazaki T, Seichi A et al (2005) Spinal stenosis in grade I degenerative lumbar spondylolisthesis: a comparative study of outcomes following laminoplasty and laminectomy with instrumented spinal fusion. J Orthop Sci 10:270–276
11. Matsudaira K, Yamazaki T, Seichi A et al (2009) Modified fenestration with restorative spinoplasty for lumbar spinal stenosis. J Neurosurg Spine 10:587–594
12. Mazanec DJ, Podichetty VK, Hsia A (2002) Lumbar canal stenosis: start with nonsurgical therapy. Cleve Clin J Med 69:909–917
13. Olmarker K, Rydevik B (1992) Single- versus double-level nerve root compression: An experimental study on the porcine cauda equina with analysis of nerve impulse conduction properties. Clin Orthop 279:35–39
14. Porter RW, Ward D (1992) Cauda equina dysfunction. The significance of two-level pathology. Spine 17:9–15
15. Spratt KF, Keller TS, Szpalski M et al (2004) A predictive model for outcome after conservative decompression surgery for lumbar spinal stenosis. Eur Spine J 13:14–21
16. Taillard W (1954) Spondylolisthesis in children and adolescents. Acta Orthop Scand 24:115–144

17. Takahashi K, Miyazaki T, Takino T et al (1995) Epidural pressure measurements: relationship between epidural pressure and posture in patients with lumbar spinal stenosis. Spine 20:650–653
18. Takahashi K, Olmarker K, Holm S et al (1993) Double-level cauda equina compression: an experimental study with continuous monitoring of intraneural blood flow in the porcine cauda equina. J Orthop Res 11:104–109
19. Voorhies RM, Jiang X, Thomas N (2007) Predicting outcome in the surgical treatment of lumbar radiculopathy using the pain drawing score, McGill short form pain questionnaire, and risk factors including psychosocial issues and axial joint pain. Spine J 7:516–524
20. Weinstein JN, Tosteson TD, Lurie JD et al (2008) Surgical versus nonsurgical therapy for lumbar spinal stenosis. N Engl J Med 358:794–810

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ORIGINAL ARTICLE

New parameters to represent the position of the aorta relative to the spine for pedicle screw placement

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Abstract Parameters of the position of the aorta in previous reports were determined for anterior surgery. This study evaluated the relative position of the aorta to the spine by new parameters, which could enhance the safety of pedicle screw placement. Three parameters were defined in a new Cartesian coordinate system. We selected an entry point of a left pedicle screw as the origin. The transverse plane was determined to include both the bases of the superior facet and to be parallel to the upper endplate of the vertebral body. A line connecting the entry points of both sides was defined as the *X*-axis. The angle formed by the *Y*-axis and a line connecting the origin and the center of the aorta was defined as the left pedicle–aorta angle. The length of a line connecting the origin and the aorta edge was defined as the left pedicle–aorta distance. Distance from the edge of the aorta to the *X*-axis was defined as the pedicular line–aorta distance. These parameters were measured preoperatively in 293 vertebral bodies of 24 patients with a right thoracic curve. We simulated the placement of the pedicle screw with variable length and with some direction error. We defined a warning pedicle as that when the aorta enters the expected area of the screw. Sensitivity analysis was performed to find the warning pedicle ratio in 12 scenarios. The left pedicle–aorta angle averaged 29.7° at the thoracic spine and −16.3° at the lumbar spine; the left pedicle–aorta distance averaged 23.7 and 55.2 mm; the pedicular line–aorta distance averaged 18.3 and 51.0 mm, respectively. The ratio of warning pedicles was consistently high at T4–5 and T10–12. When a left pedicle screw perforates an anterior/lateral wall of the vertebral body, the aorta may be at risk. These new parameters enable surgeons to intuitively understand the position of the aorta in surgical planning or in placement of a pedicle screw.

Keywords Scoliosis · Pedicle screw · Aorta · Computed tomography

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Introduction

Several authors have reported serious injuries of the aorta due to inappropriate placement of screws or plates in anterior surgery [8, 9]. Sucato et al. [10] reported that 12% (13/106) of vertebral screws in right thoracic scoliosis created some contour defect in the aorta on the contralateral side of the vertebral body, although patients had no sequela. They subsequently analyzed the position of the aorta in patients with scoliosis compared to those with non-scoliotic spine and found that the aorta often resides on the lateral side of the vertebral body and concluded that a potential risk of the aorta by a vertebral screw increases in the scoliotic spine. Maruyama et al. [7] studied the spatial relations between the spine and the aorta in adolescent idiopathic scoliosis and concluded that the aorta can be located in the direction of the screw passage in 33 of 40 vertebrae (83%) between T6 and T9. These studies,

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however, paid less attention to the relationship between the aorta and a pedicle screw. Accordingly, parameters describing the position of the aorta in these reports were not intuitive and surgeons have had difficulty utilizing these values in posterior surgery. The purpose of the present study was to evaluate the relative position of the aorta to the spine by new parameters, which can enhance the safety of pedicle screw placement.

Materials and methods

Thirty-seven patients with scoliosis underwent posterior instrumentation and fusion at the University Hospital from 2005 to 2007. Patients with congenital scoliosis were excluded. A total of 24 patients with a right thoracic curve were included in this study. Scoliosis was idiopathic in 17 patients, Chiari-syrinx in 2, Marfan syndrome in 2, multiple epiphyseal dysplasia in 1, Noonan syndrome in 1, and tuberous sclerosis in 1. Age at surgery was 10–29 (mean 17.1) years; 19 patients were women and 5 were men. Lenke's classification of scoliosis [4] was type 1 in eight patients, type 2 in five, type 3 in two, type 4 in four, type 5 in one, and type 6 in four. Preoperative Cobb angle averaged 66.4° (50°–103°). The apex vertebra ranged from T5 to T10 (median T10). All patients were treated by posterior correction and fusion by pedicle screw instrumentation. One patient with a curve of 103° had undergone anterior release before posterior spinal fusion. Computed tomography was taken before surgery and pedicle screws were placed with guidance of the CT-based navigation system. Postoperative Cobb angle averaged 20.3° (11°–39°).

A computer tomography was taken from the upper thoracic to the lower lumbar spine with a width of 1.25 mm for navigation. All DICOM data were transferred to a personal computer and analyzed by DICOM software (ExaView LITE: ©Ziosoft, Tokyo, Japan). We defined three parameters in a new Cartesian coordinate system and those parameters from T4 to L4 were measured in 293 vertebral bodies of 24 patients. We selected the middle of the base of the left superior facet as the origin of this coordinate system (Fig. 1), because the most probable threat to the aorta by a pedicle screw is on the left side at the thoracic spine. The transverse plane was determined to include both the bases of the superior facet and to be parallel to the upper endplate of the vertebral body. A line connecting the middle points of both bases of the superior facets is defined as the pedicular line (PL) (*X*-axis). The *Y*-axis perpendicular to the *X*-axis is drawn ventrally from the origin. The angle formed by the *Y*-axis and a line connecting the origin and the center of the aorta is defined as the left pedicle–aorta angle length of a line connecting the origin and the edge of the aorta as the left pedicle–aorta distance, and distance from the edge of the aorta to the *X*-axis as the pedicular line–aorta distance. Moreover, we break down the left pedicle–aorta distance into the *X*- and *Y*-unit. The *X*-unit is the rectangular component of the left pedicle–aorta distance to the *X*-axis and the *Y*-unit is that to the *Y*-axis.

We simulated placement of the pedicle screw with a direction different from the ideal trajectory. Sensitivity analysis was performed by changing the direction error and the length of the screw independently. The direction error started from 10° up to 30° with 10° increments (three scenarios). The length of the screw started from 25 to 40 mm with increments of 5 mm (four scenarios). We set up a total of 12 scenarios (three by four). We defined a warning pedicle as that when the aorta enters the expected area of the screw. The ratio of warning pedicles was calculated from T4 to L4 in the 12 scenarios (Fig. 2). From the repeatability test from our previous study, interclass correlation coefficients were 0.922–0.957 in the intraobserver measurement and 0.896–0.929 (0.864–0.961) in the interobserver measurement [12].

To determine the relationship of the location of the aorta and the characteristics of scoliosis, the Cobb angle of the main thoracic curve, apical vertebral translations of the main thoracic curve, and the angle at T5–T12 in the sagittal plane were measured, and correlations between these

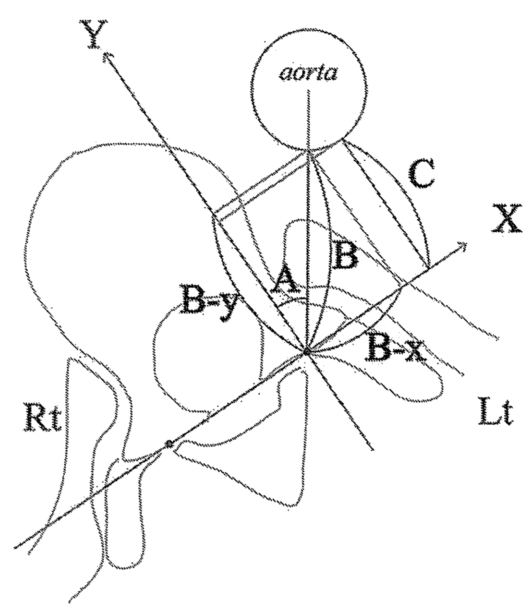

Fig. 1 Measurement of new parameters. The origin is set at the middle of the base of the left superior facet. A line joining the middle points of both bases of the superior facets is defined as the *X*-axis (*the pedicular line*). The *Y*-axis, perpendicular to the *X*-axis, is drawn ventrally from the origin. *A* The left pedicle–aorta angle. *B* The left pedicle–aorta distance. *B-x* the *X*-unit of the left pedicle–aorta distance. *B-y* the *Y*-unit of the left pedicle–aorta distance. *C* the pedicular line–aorta distance

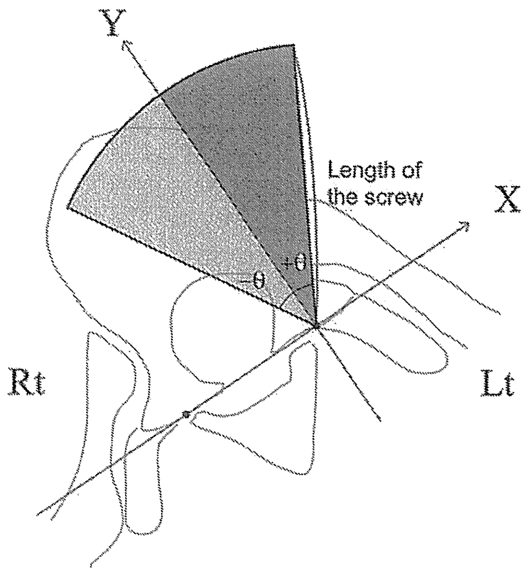

Fig. 2 The expected area of the pedicle screw. We simulated the pedicle screw placement with some direction error ($\pm\theta$) and the variable length (length of the screw) with sensitivity analysis. We defined a warning pedicle as that when the aorta enters this zone

parameters and the X-and Y-unit of the left pedicle–aorta line at the apex were calculated.

Results

The relative position of the aorta to the spine changed dramatically at the thoracic spine (Table 1; Fig. 3). The left pedicle-aorta angle spanned from −46° to 78° (average 29.7°) at the thoracic spine and from −38° to 13° (average −16.3°) at the lumbar spine; the left pedicle–

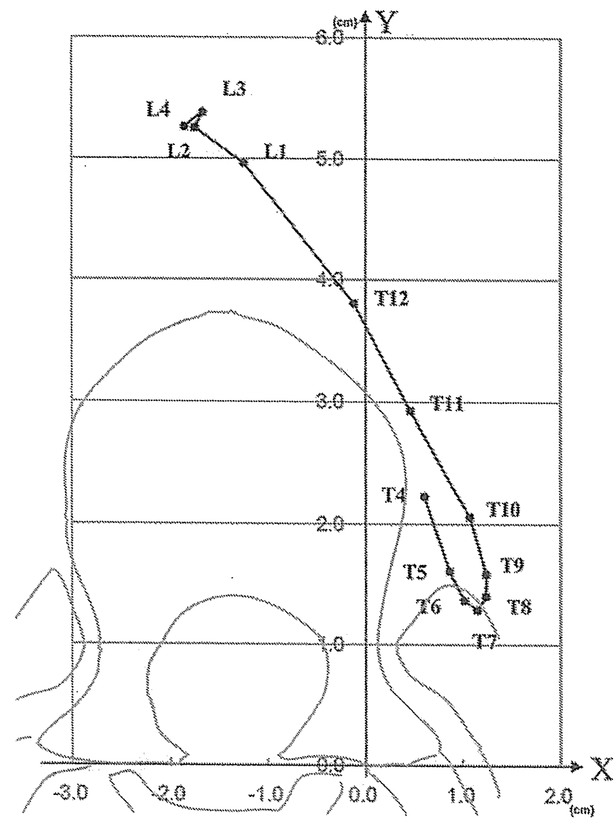

Fig. 3 The average course of the aorta relative to the spine. The origin is set at the middle of the base of the left superior facet. A line joining the middle points of both bases of the superior facets is defined as X-axis. The aorta begins to be seen from T4. It descends laterally and posteriorly and turns back at T7. At T12, the aorta is in front of the left pedicle and moves to the right side at the lumbar level. Attention should be paid to the spine drawn in the figure, because the size of the spine changed considerably at the level of the spine

Table 1 Distribution of the left pedicle-aorta angle, the left pedicle-aorta distance, and the pedicular line-aorta distance

	Left pedicle–aorta angle (°)	Left pedicle–aorta distance (mm)	The pedicular line–aorta distance (mm)
T4	20.1 ± 22.7	24.5 ± 6.2	20.9 ± 9.7
T5	32.1 ± 20.3	19.4 ± 4.4	14.1 ± 8.5
T6	39.5 ± 17.3	17.8 ± 3.5	10.9 ± 7.2
T7	43.8 ± 13.6	17.6 ± 3.6	10.1 ± 6.3
T8	42.8 ± 11.9	19.0 ± 4.2	11.4 ± 6.5
T9	40.0 ± 12.8	20.6 ± 4.9	13.6 ± 7.2
T10	30.2 ± 15.1	24.0 ± 6.4	19.2 ± 8.6
T11	13.0 ± 19.9	31.5 ± 8.1	29.1 ± 11.0
T12	0.3 ± 15.6	39.3 ± 8.3	36.9 ± 8.4
L1	-12.9 ± 13.3	52.4 ± 7.1	48.3 ± 7.0
L2	-17.7 ± 10.3	56.2 ± 6.2	51.2 ± 5.2
L3	-16.9 ± 6.8	56.7 ± 5.4	52.9 ± 4.2
L4	-19.4 ± 5.0	56.0 ± 5.0	52.4 ± 7.4

aorta distance ranged from 11 to 52 mm with an average of 23.7 mm and from 36 to 72 mm with an average of 55.2 mm, respectively; the pedicular line–aorta distance ranged from −4 to 59 mm (average 18.3 mm) and from 33 to 75 mm (average 51.0 mm), respectively. From the cephalad to the caudal direction, the aorta was seen at the antero-lateral position of the vertebral body of T4 or T5. The aorta moved to the left side laterally and posteriorly as it descended, changing its course at T7 and moving medially and anteriorly. It located in front of the vertebral body at the left T12 pedicle. At the lumbar spine, the aorta moved to the right side.

The ratio of warning pedicles increased as the direction error or the screw length increased (Fig. 4). When the direction error was within 30° and the screw length was 40 mm, the ratio was highest at T4 with 69%, followed by T11 (67%), T5 (54%), T10 (46%) and T12 (39%), and this trend was consistent in any scenario.

No parameter of the main thoracic curve correlated with the *X*-unit of the left pedicle–aorta distance at the apex.

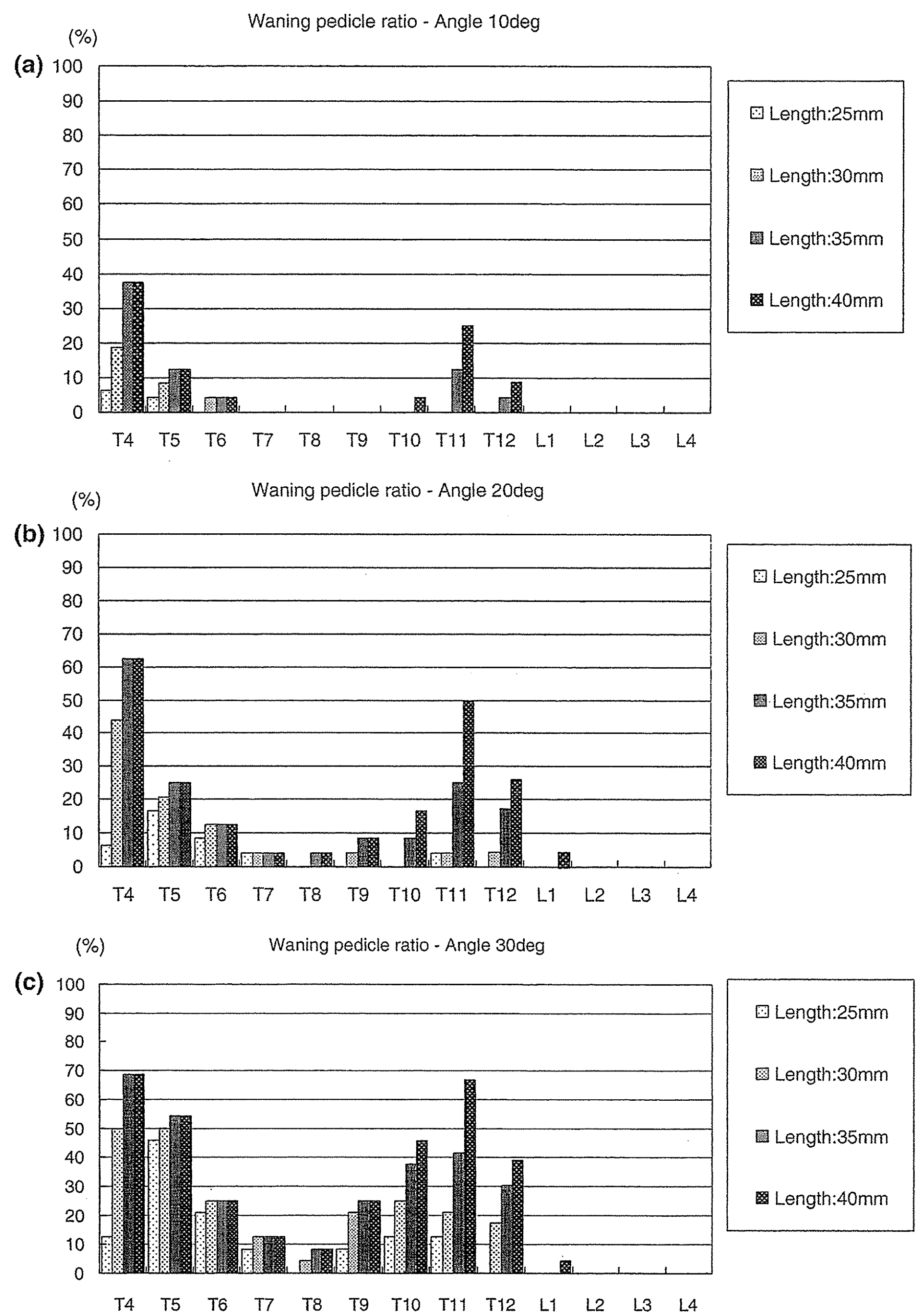

Fig. 4 Distribution of warning pedicle ratios from T4 to L4 in 12 scenario. In any scenario, there was a high percentage of warning pedicles at the thoracic spine except at T7 and T8. **a** The warning pedicle ratio when the direction error is within 10° and the screw length changes from 25 to 40 mm. **b** The warning pedicle ratio when the direction error is within 20° and the screw length changes from 25 to 40 mm. **c** The warning pedicle ratio when the direction error is within 20° and the screw length changes from 25 to 40 mm

Sagittal angle at T5–T12 in the sagittal plane significantly correlated with the Y-unit ("anterior–posterior" direction for the spine) of the left pedicle–aorta distance at the apex (-0.44; $p = 0.03$).

Discussion

Liljenqvist et al. [5] measured the distance from the aorta to the vertebral body, and reported that the closest distance averaged 6–7 mm between T4 and T9 and <5 mm between T10 and L4. Sucato and Duchene [11] analyzed the position of the aorta in patients with idiopathic scoliosis in magnetic resonance scans and found that the thoracic aorta in idiopathic scoliosis is positioned more posteriorly and laterally compared with straight spines. From their analysis, the aorta begins to be seen as the aortic arch in front of the T4 vertebral body and changes its position posteriorly and laterally as it descends. The aorta turns back anteriorly and medially at the apical region and passes in front of the T12 through the hiatus of the diaphragm. The present study supports their analyses.

Vaccaro et al. [13] analyzed a non-scoliotic thoracic spine and found that the aorta and the esophagus are at greatest risk of injury when a pedicle screw penetrates an anterior cortex of the vertebral body. Liljenqvist et al. [6] analyzed 22 patients with idiopathic scoliosis by computed tomography postoperatively. They found that 3 of 120 pedicle screws penetrated the anterior vertebral cortex and 1 of these three screws was replaced because of its direct proximity to the thoracic aorta.

When a pedicle screw is placed by a free-hand technique [3] or with a fluoroscope, the direction of placement largely depends on several landmarks of the explored surface of the spine: facet joints, transverse processes and laminae. Our new parameters defined by both sides of superior facet are easy to comprehend in posterior surgery. Additionally, we could compare the relative risk of pedicle screw placement between spine levels in various settings by the sensitivity analysis.

The present study elucidated that the aorta usually stays on the anterior or left-lateral side of the vertebral body at T4, T5 and at T10–T12, and a small breach of a pedicle screw outside the vertebral body at these levels may result in indentation of the aorta. Faro et al. [1] studied the influence of indentation of the aorta by a screw in their bovine model and found that the major impingement of vertebral screws on the aorta caused acute and chronic histopathologic and biomechanical changes in the vessel wall. Though sequelae of moderate to mild indentation of the aorta have not yet been known, screws will stay inside the body for over tens of years in this young population. It is recommended that any screw either in anterior or in posterior surgery be placed away from the aorta.

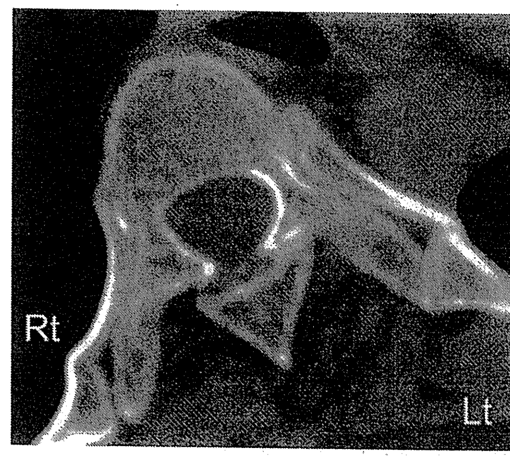

Fig. 5 A case with a typical position of the aorta around the apex level. Though a distance to the left base of the superior facet (an insertion point of a pedicle screw) is closer than other levels, the aorta often resides in the most lateral position from the spine and allows wider maldirection of the pedicle screw

The present study shows that the aorta at the middle thoracic spine is often located away from the spine and resides in front of a left rib (Fig. 5), which leads to a low percentage of dangerous pedicles at T7 and T8. However, in turn, the spinal cord deviates to the left concave pedicles at the apical area at the right thoracic spine [5]. Moreover, the aorta may not stay in the same position. Huitema et al. [2] examined 50 patients by computed tomography or magnetic resonance scans before surgery, and reported that the aorta moves more anteromedially in a prone position than in a supine position especially at levels T5–T10. Their study indicates that the aorta is fairly mobile at the mid-thoracic level when a subject changes his position. Though the present study showed a relative safety of the aorta at T6–T9, the aorta might reside closer to the spine when a subject is at another position. Admittedly, segmental pedicle screw instrumentation is a most powerful construct for correction and maintenance in spinal deformity. Surgeons, however, must be vigilant about the positions of the aorta and the spinal cord in placement of pedicle screws, especially on the left side, and screw breach may necessitate reoperation for replacement.

In summary, new parameters enable surgeons to intuitively understand the position of the aorta in their preoperative planning or during placement of a pedicle screw. When a left pedicle screw perforates an anterior/lateral wall of the vertebral body, the aorta may be at risk, especially at T4, T5 and T10–T12.

References

1. Faro FD, Farnsworth CL, Shapiro GS et al (2005) Thoracic vertebral screw impingement on the aorta in an in vivo bovine model. Spine 30(21):2406–2413
2. Huitema GC, Cornips EM, Castelijns MH et al (2007) The position of the aorta relative to the spine: is it mobile or not? Spine 32(12):1259–1264
3. Kim YJ, Lenke LG, Bridwell KH et al (2004) Free-hand pedicle screw placement in the thoracic spine: is it safe? Spine 29:333–342
4. Lenke LG, Betz RR, Harms J et al (2001) Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. J Bone Joint Surg Am 83(8):1169–1181
5. Liljenqvist UR, Allkemper T, Hackenberg L et al (2002) Analysis of vertebral morphology in idiopathic scoliosis with use of magnetic resonance imaging and multiplanar reconstruction. J Bone Joint Surg Am 84(3):359–368
6. Liljenqvist UR, Halm HF, Link TM (1997) Pedicle screw instrumentation of the thoracic spine in idiopathic scoliosis. Spine 22(19):2239–2245
7. Maruyama T, Takeshita K, Nakamura K et al (2004) Spatial relations between the vertebral body and the thoracic aorta in adolescent idiopathic scoliosis. Spine 29:2067–2069
8. Matsuzaki H, Tokuhashi Y, Wakabayashi K et al (1993) Penetration of a screw into the thoracic aorta in anterior spinal instrumentation. A case report. Spine 18:2327–2331
9. Ohnishi T, Neo M, Matsushita M et al (2001) Delayed aortic rupture caused by an implanted anterior spinal device. J Neurosurg 95(2 Suppl):253–256
10. Sucato DJ, Kassab F, Dempsey M (2004) Analysis of screw placement relative to the aorta and spinal canal following anterior instrumentation for thoracic idiopathic scoliosis. Spine 29(5):554–559
11. Sucato DJ, Duchene C (2003) The position of the aorta relative to the spine: a comparison of patients with and without idiopathic scoliosis. J Bone Joint Surg Am 85(8):1461–1469
12. Takeshita K, Maruyama T, Chikuda H et al (2009) Diameter, length, and direction of pedicle screws for scoliotic spine: analysis by multiplanar reconstruction of computed tomography. Spine 34:798–803
13. Vaccaro AR, Rizzolo SJ, Balderston RA et al (1995) Placement of pedicle screws in the thoracic spine. Part II. An anatomical and radiographic assessment. J Bone Joint Surg Am 77(8):1200–1206

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Modified fenestration with restorative spinoplasty for lumbar spinal stenosis

Technical note

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The authors developed an original procedure, modified fenestration with restorative spinoplasty (MFRS) for the treatment of lumbar spinal stenosis. The first step is to cut the spinous process in an L-shape, which is caudally reflected. This procedure allows easy access to the spinal canal, including lateral recesses, and makes it easy to perform a trumpet-style decompression of the nerve roots without violating the facet joints. After the decompression of neural tissues, the spinous process is anatomically restored (spinoplasty). The clinical outcomes at 2 years were evaluated using the Japanese Orthopaedic Association (JOA) scale and patients' satisfaction. Radiological follow-up included radiographs and CT.

Between January 2000 and December 2002, 109 patients with neurogenic intermittent claudication with or without mild spondylolisthesis underwent MFRS. Of these, 101 were followed up for at least 2 years (follow-up rate 93%). The average score on the self-administered JOA scale in 89 patients without comorbidity causing gait disturbance improved from 13.3 preoperatively to 22.9 at 2 years' follow-up. Neurogenic intermittent claudication disappeared in all cases. The patients' assessment of treatment satisfaction was "satisfied" in 74 cases, "slightly satisfied" in 12, "slightly dissatisfied" in 2, and "dissatisfied" in 1 case. In 16 cases (18%), a minimum progression of slippage occurred, but no symptomatic instability or recurrent stenosis was observed. Computed tomography showed that the lateral part of the facet joints was well preserved, and the mean residual ratio was 80%. The MFRS technique produces an adequate and safe decompression of the spinal canal, even in patients with narrow and steep facet joints in whom conventional fenestration is technically demanding. *(DOI: 10.3171/2009.2.SPINE08358)*

KEY WORDS • **decompression surgery** • **laminectomy** • **fenestration** • **lumbar spinal stenosis**

LAMINECTOMY has been the standard surgical treatment for lumbar spinal stenosis (LSS).[20] An advantage of conventional laminectomy is that it provides good visibility and working space by removing posterior elements, including spinous processes and the interspinous-supraspinous ligament complex, which makes possible sufficient decompression. However, resection of the osteoligamentous structure sometimes causes secondary spinal instability.[1,7,14]

Fenestration has been developed to solve this problem of laminectomy.[19] This method, which does not remove the midline osteoligamentous structure, has an advantage in that it preserves spinal stability.[1,20] However, in fenestration, preserved midline structures limit access to the nerve tissues, leading to insufficient decompression in lateral recesses, especially in patients with narrow and steep facet joints.[12] The potential risk for neural injury in a small working space is also a problem.[1,13,20]

Against this background, we have developed an original surgical procedure, "modified fenestration with restorative spinoplasty" (MFRS), which has advantages of both laminectomy and fenestration, 2 major posterior decompression methods. Since 2001, we have used this method in the treatment of patients with symptomatic LSS, excluding patients in whom fusion is recommended, such as those with Meyerding Grade II spondylolisthesis.[9] In this present study, we describe our technique and report clinical results of 2 years of follow-up.

Methods

Patient Population

Patients with LSS accompanied by neurogenic intermittent claudication, in whom conservative therapy for at least 3 months was not effective, were considered to

Abbreviations used in this paper: JAO = Japanese Orthopaedic Association; MFRS = modified fenestration with restorative spinoplasty; LSS = lumbar spinal stenosis.

be candidates for MFRS. Stenosis was confirmed by MR imaging, myelography, and CT myelography. Patients with LSS who had 1) Meyerding Grade II degenerative spondylolisthesis, 2) degenerative scoliosis with a Cobb angle[2] > 20°, 3) spondylolysis, 4) posttraumatic stenosis, or 5) restenosis after decompression surgery were excluded because they were considered candidates for fusion surgery. Between January 2000 and December 2002, 109 patients with the inclusion criteria underwent MFRS. Of these patients, 101 were followed up for at least 2 years (follow-up rate 93%). Of the 8 patients who were lost to follow-up, 2 died due to lung cancer and heart failure, 3 patients were relocated, and 3 could not be contacted. Of the 101 patients for whom adequate follow-up data were available, 12 patients with gait disturbance due to cerebral infarction, myelopathy, or dementia were excluded from the analysis. These conditions developed during the postoperative follow-up period. The remaining 89 patients constituted the study group.

Surgical Technique

While preserving the supra- and interspinous ligaments, the posterior portion of vertebral arches is exposed, keeping the capsule of the facet as intact as possible. The first step is to cut the spinous process in an L-shape at the proximal one-third using a bone cutter (Fig. 1A). The distal two thirds of the cut spinous process are caudally reflected together with the distal interspinous-supraspinous ligament complex. This procedure creates an ample working space to the spinal canal including lateral recesses and the entry zone of the foramina. Surgeons can perform an adequate decompression of the nerve roots from the opposite side using an osteotome or Kerrison rongeurs and make a trumpet-style decompression of the spinal canal while preserving the cranial parts of the vertebral arches and the lateral parts of the facet joints (Fig. 1B). The same procedure can be repeated when multiple-level decompression is necessary (Fig. 1C). After decompressing the neural tissues, the spinous process is repositioned and reconstructed with tight suturing using polyethylene cable[4] and nonabsorbable suture material (restorative spinoplasty) (Fig. 1D). We first make 2 small holes in the caudal portion of the spinous process. Then, we pass the polyethylene cable around the cranial margin of the residual spinous process and through the holes we made. The split spinous process is approximated by tightening the cable and tying it on the lateral surface. After reconstruction of the spinous process described above, we suture the

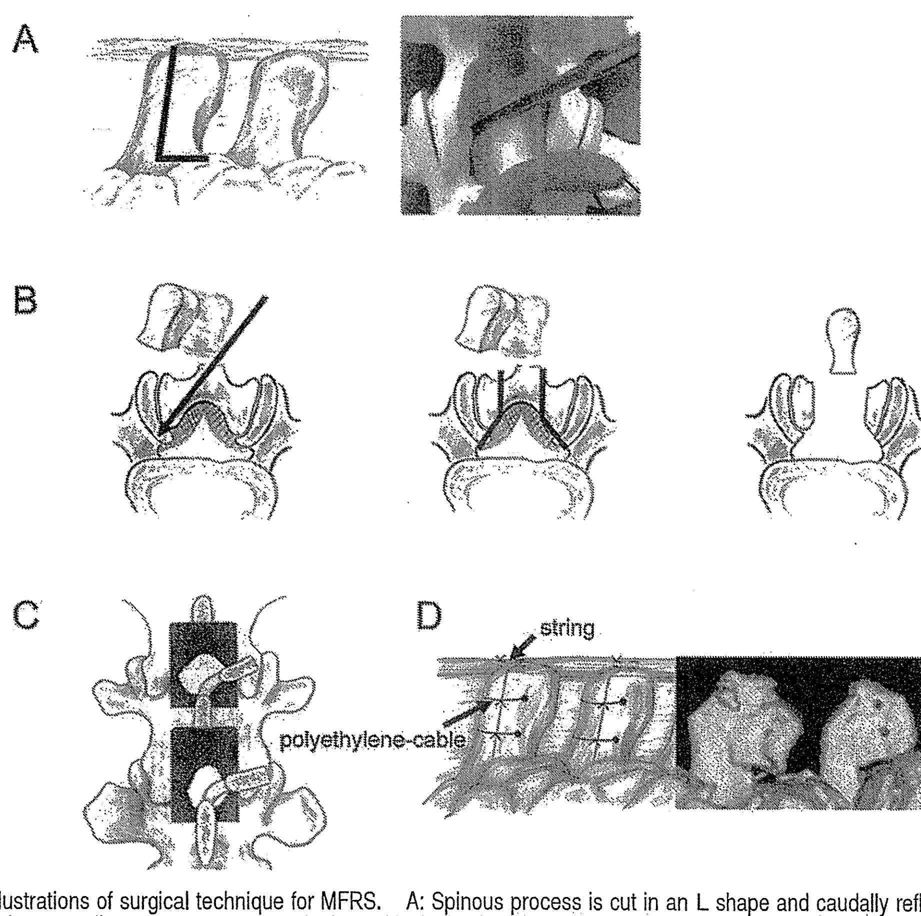

FIG. 1. Illustrations of surgical technique for MFRS. A: Spinous process is cut in an L shape and caudally reflected. B: Temporal spinotomy allows easy access to spinal canal including lateral recesses and makes it easy to perform a trumpet-style decompression. C: Spinotomy and laminotomy can be repeated to make multiple-level decompression. D: After the decompression, the spinous process is repositioned and reconstructed with tight suturing.

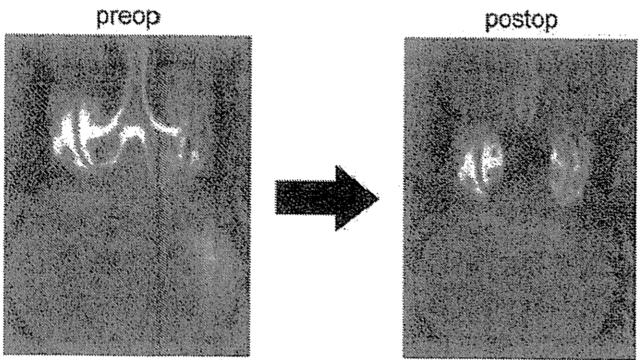

FIG. 2. Preoperative *(left)* and postoperative *(right)* CT scans. *Left:* Preoperative CT shows severe spinal stenosis with narrow and steep facet joints. *Right:* Postoperative CT shows a sufficient trumpeted decompression of the spinal canal with preservation of the facet joints.

supraspinous ligament with a nonabsorbable suture material using the mattress suture technique. Anatomical reduction is achieved between the residual spinous process and the repositioned spinous process. Using this technique, adequate decompression can be performed even in patients with narrow and steep facet joints and/or severe central stenosis in whom sufficient decompression with facet preservation is difficult to achieve by conventional fenestration (Fig. 2).

The patient is allowed to sit up and walk on the 1st or 2nd postoperative day with a soft lumbar support. This support is used for 3 months to prevent excessive flexion of the lumbar spine.

Clinical Outcomes and Radiographic Assessment

The clinical outcomes at 2 years were evaluated using 1) the JOA scoring system (Table 1) with the assessment performed by self-administration[6] and 2) patient satisfaction. Patient satisfaction was evaluated by self-assessment of 4 grades (satisfied, slightly satisfied, slightly dissatisfied, and dissatisfied). Postoperative complications were also investigated.

Radiological follow-up included radiographs and CT scans. To investigate pre- and postoperative radiological findings, we defined degenerative spondylolisthesis as a condition of > 5% anterior slippage according to the Taillard method,[16] and defined degenerative scoliosis as a condition of the Cobb angle > 10°. Shape of the inferior facet was assessed by anteroposterior radiograph and classified according to the system of Tsunoda:[17] X-type, M-type, and W-type (Fig. 3); M-type and W-type were defined as the narrow and steep facet joints.

We measured the segmental sagittal alignment (Fig. 4), the intervertebral range of motion (Fig. 5), and the percentage of slip at the decompressed levels using both pre- and postoperative radiographs, including dynamic views. Postoperative progression of slippage was evaluated at 2-year follow-up; > 5% increase of slippage was defined as significant progression. Postoperative preservation of the facet was evaluated by a comparison between preoperative CT and postoperative CT performed 1 week after surgery (Fig. 6). The measurement was made at 3 levels

TABLE 1: Summary of the JOA scoring system, excluding bladder function*

Items	Score
subjective symptoms (9 points)	
low-back pain	
none	3
occasionally mild	2
always present or sometimes severe	1
always severe	0
leg pain &/or numbness	
none	3
occasionally mild	2
always present or sometimes severe	1
always severe	0
walking ability	
normal	3
able to walk >500 m, w/ pain/numbness/weakness present	2
unable to walk 500 m due to pain/numbness/weakness	1
unable to walk 100 m due to pain/numbness/weakness	0
objective signs (6 points)	
SLR	
normal	2
30–70°	1
<30°	0
sensory function	
normal	2
mild disturbance	1
apparent disturbance	0
motor function	
normal (MMT normal)	2
slightly decreased muscle strength (MMT good)	1
marked decreased muscle strength (MMT < fair)	0
restriction of ADL (14 points)†	
none	2
moderate	1
severe	0
total score	29

* ADL = activities of daily living; MMT = manual muscle test; SLR = straight-leg raising.
† Activities of daily living include the following: turning over while lying down, standing, washing one's face, leaning forward, the ability to sit for approximately 1 hour, ability to lift or hold heavy objects, and ambulatory ability.

of each facet joint: the caudal edge of the upper vertebra, disc level, and the cranial edge of the lower vertebra. The least residual ratio among 3 values for each facet joint was used. Union of the reconstructed spinous process was evaluated by lateral radiograph as follows: Grade 1, os-