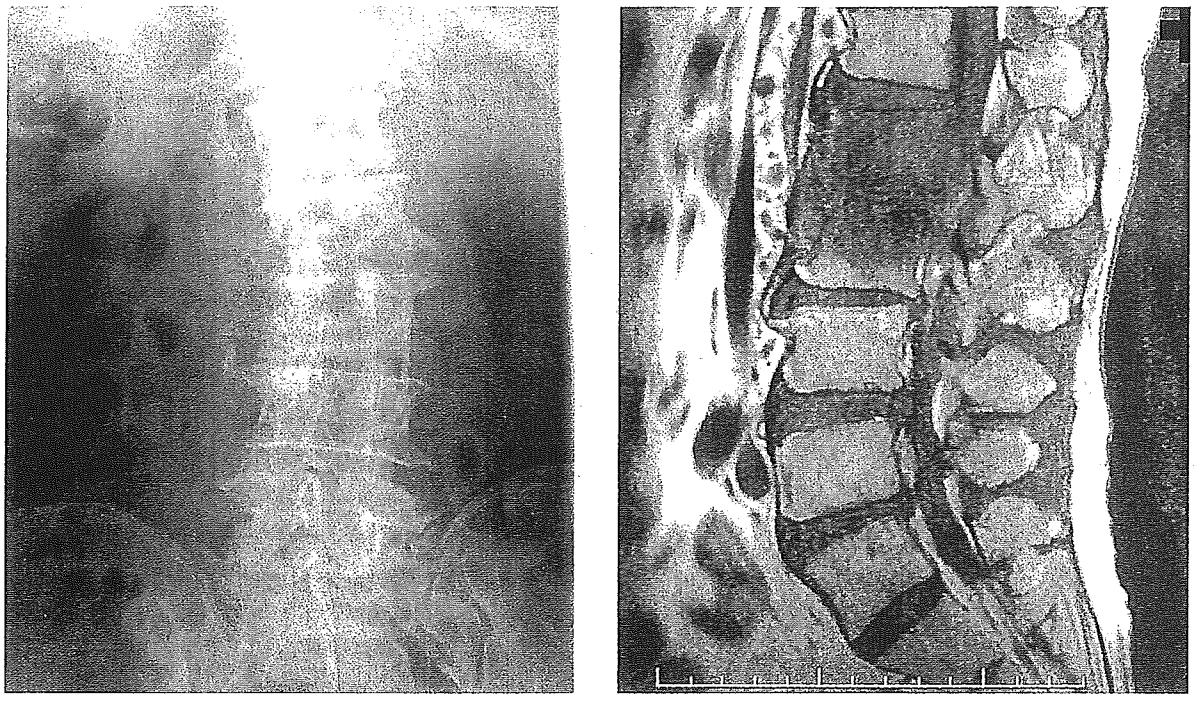
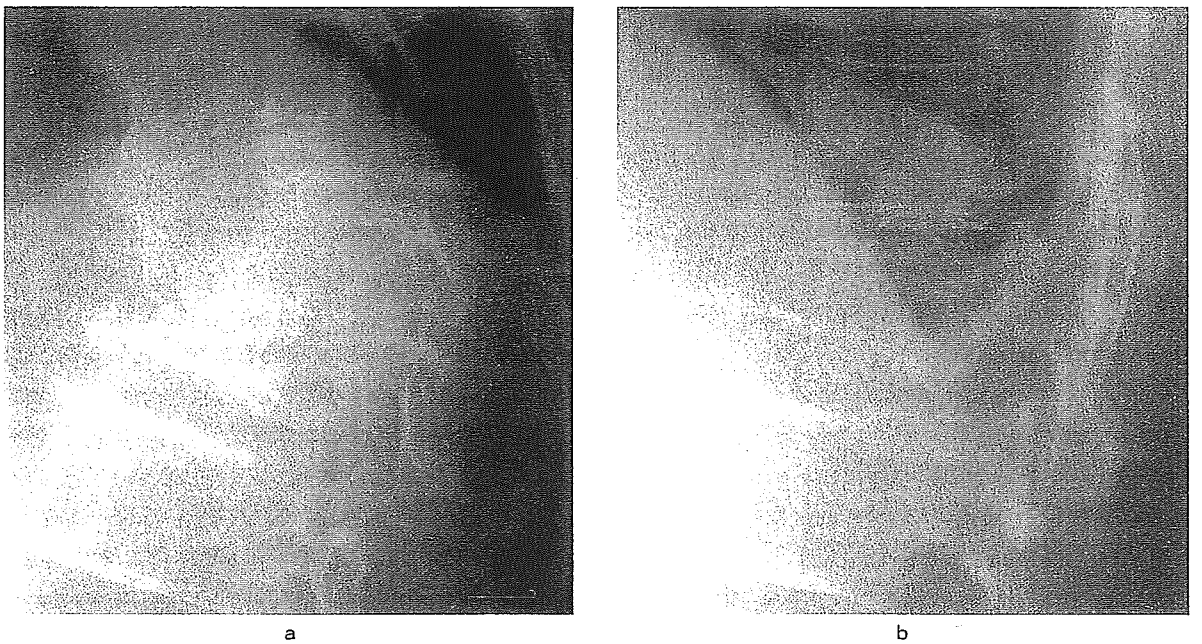


a　　b

図 10-2-16　L 2-3 結核性脊椎炎
a：単純 X 線正面像　b：MRI T 1 強調矢状断像



a　　b

図 10-2-17　concertina collapse の像を呈した結核性脊椎炎
a：単純 X 線側面像(屈曲位)　b：単純 X 線側面像(伸展位)

b. *化膿性(細菌性)脊椎炎*

大部分が血行性感染で，まれに椎間板手術や検査による直接感染がある．起炎菌は黄色ブドウ球菌が最も多いが，近年菌種は多様化しすべての菌が原因になり得る．抗生物質乱用や易感染性宿主増加と共に弱毒菌やMRSA感染の報告が増えている．発症には宿主の抵抗力が大いに関係し，高齢者，糖尿病，肝硬変，ステロイド治療，悪性腫瘍，透析などは危険因子である．罹患部位は腰椎が最も多く，次に胸椎で，頚椎はまれである．膿瘍がみられることはあるが，結核性脊椎炎のような流注膿瘍の形成は少ない．

臨床症状

発熱・激しい疼痛・*脊柱不撓性*を示す急性型，微熱程度で臨床症状も軽度で比較的緩慢に経過する亜急性型，発熱がなく発症経過の不明な潜行型の3型に分類される．起炎菌多様化を反映して急性型は減少傾向で，亜急性型，潜行型の割合が増えている．脊髄や神経根圧迫による神経症状を呈する例もある．

診断

急性期は白血球増加，赤沈亢進，CRP陽性などの炎症所見を示すが，亜急性期以降の炎症所見は軽度から中等度で正常のこともあり，これらの数値は病勢診断に重要である．本疾患を疑う時は血液培養を実施する．ただし抗生物質をすでに開始している場合をはじめ，起炎菌が必ず検出されるわけではない．

単純X線で急性期には所見を認めないことがあり，発症後3～4週で初期変化として椎間板腔狭小化と椎体縁不整像があらわれる．2～5ヵ月で反応性骨硬化，椎体間架橋形成が起こり，最終的には椎体癒合に至る．MRIはX線で変化のみられない早期からの診断に有用で，炎症性浮腫を反映し罹患椎体は健常椎体に比しT1強調像で低信号，T2強調像で高信号を呈する．CTでは椎体の破壊，周囲の軟部組織腫脹が認められる．膿瘍壁が造影されるが，これは結核性脊椎炎の方が特徴的である．

画像や血液検査で脊椎の感染が疑われるが血液培養陰性の場合，特に抗生物質に対する反応が不良の時には，起炎菌同定のための生検を考慮すべきである．

治療

起炎菌の根絶と脊柱の安定化が目標となり，安静と感受性のある抗生物質投与で多くはこれを達成できる．ただし起炎菌同定が困難なことも多く，その場合には広域スペクトルの抗生物質を投与し，効果判定を臨床症状，血液炎症所見で行う．神経麻痺合併，骨破壊による脊柱変形著明，抗生物質に対する反応不良，診断困難な場合は外科治療の適応となる．その目的は感染病巣除去，神経組織除圧，脊柱支持性再建である．手術で採取した病巣組織は培養と感受性検査を実施し，抗生物質の併用は必須である．なお化膿性脊椎炎でのinstrumentation使用はコンセンサスが得られていない．

c. *真菌性脊椎炎*

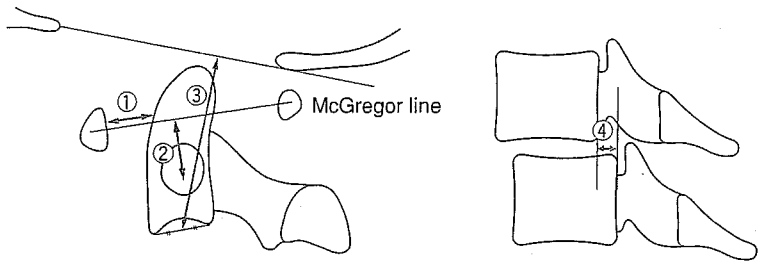
高齢者や免疫力低下の患者が増加していることを反映し，真菌による脊椎炎も経験されるようになった．臨床症状に特異的なものはなく，結核性脊椎炎や弱毒菌による化膿性脊椎炎に類似し鑑別が問題になる．真菌性脊椎炎はMRIで辺縁造影効果を示すことがあり，結核性脊椎炎との鑑別は容易でない．確定診断は病巣組織より真菌を証明することである．治療は安静と抗真菌薬投与による保存治療が主体である．

2. リウマチ性脊椎炎

関節リウマチ(RA)脊椎病変の好発部位は上位頚椎だが，RA重症例では中下位頚椎や胸腰椎にも病変が出現する．RAによる滑膜炎は，脊椎の滑膜関節である環軸関節，椎間関節に生じ，また靱帯付着部にも炎症が生じてこれが椎間板や椎体に波及し，亜脱臼，あるいは椎体破壊を引き起こす．

上位頚椎の代表病変は*環軸椎亜脱臼* atlantoaxial subluxation(AAS)と*軸椎垂直亜脱臼* vertical subluxation of the axis(VS)で，発生機序は以下の通りである．まず，正中環軸関節の滑膜炎により前方安定性を担う横靱帯が機能不全に陥り，環椎前方亜脱臼を生じる．外側環軸関節にも破壊が起こると

図 10-2-18　頚椎亜脱臼診断のための計測法と基準



環軸椎前方亜脱臼：①環椎歯突起間距離（atlantodental distance: ADD）≧3mm
軸椎垂直亜脱臼：②Ranawat法≦13mm
③Redlund-Johnell法≦34mm（男性），≦28mm（女性）
軸椎下亜脱臼：④すべり距離≧3mm

側方や回旋性亜脱臼を生じ，歯突起の高度破壊や病的骨折を来すと後方亜脱臼を生じる．VS は外側環軸関節に加え後頭環椎関節の骨破壊により生じ，その破壊程度が亜脱臼の重症度を左右する．中下位頚椎病変（*軸椎下亜脱臼* subaxial subluxation：SS）は，椎間関節の破壊，棘突起の菲薄化・骨折，椎間板や椎体への炎症波及などで不安定性が起こり生じる．RA 重症例では急速に椎体破壊を生じる例があり，椎体骨髄病変の関与が推測されている．胸腰椎病変も同様で，椎間関節破壊が主体のすべりと椎体圧潰に分けられるが，疾患自身と薬剤（ステロイド）による骨粗鬆症の影響も加わる．

臨床症状

脊椎運動器官としての症状，罹患部位での神経圧迫症状に分けられる．前者は，罹患部疼痛，可動時軋音，可動制限などである．後者は，運動知覚麻痺と神経根性疼痛であり，頚椎での脊髄障害は四肢関節罹患を伴う RA 患者にとっては重度の ADL 障害をもたらす．また脳幹・上位頚髄が障害されると，呼吸や嚥下・構音障害を生じ，時に致死的になり，突然死の報告もある．特殊な症状として椎骨動脈血流不全の症状（めまい，耳鳴り，悪心など）がある．

診断

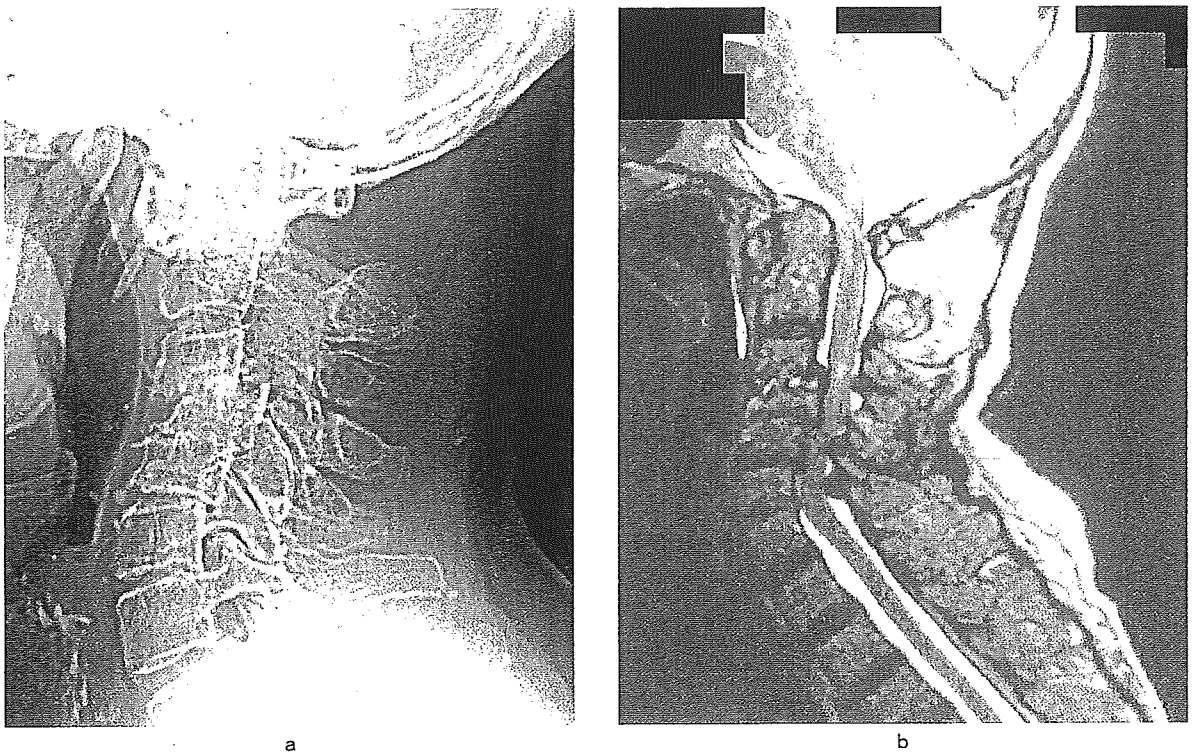
RA 患者の反射や筋力などの神経症状を把握することは，四肢関節破壊のため困難なことが多いが，関節変形の進行が少ないにもかかわらず，しびれを伴って ADL 障害が進行した際には脊髄障害を念頭に置く．

各種亜脱臼の診断には，単純 X 線像が基本になる．AAS の初期には頚椎伸展，あるいは中間位では整復されるので，屈曲位での側面撮影が必要である．主な計測法と診断基準を図 10-2-18 に示す．X 線では歯突起のびらん・骨折，椎間板腔狭小化，椎体終板びらん，椎体圧潰や癒合，椎間関節びらん，棘突起菲薄化・骨折などの所見に注意する（図 10-2-19a）．脊椎病変の評価には MRI が有用で，リウマチ性肉芽組織（パンヌス）や脳幹部を含めた脊髄圧迫状態の把握にすぐれる（図 10-2-19b）．CT も有用で，三次元画像や任意面での再構成画像で骨性の亜脱臼や変形の把握ができ，手術のプラニングに役立つ．

治療

装具治療は局所の疼痛緩和に効果を示すことがあるが，病変の発生・進行予防，脊髄症状改善に対する効果は示されていない．外科治療の適応は，脊髄症状の出現・進行，保存治療に抵抗性の強い疼痛，椎骨動脈血流不全の症状である．外科治療には神経圧迫病変の除去と脊椎安定化が求められ，整復位での固定術，あるいは整復困難な病変には椎弓切除を主とする除圧に固定術が加えられる．また RA 脊椎病変は単なる安定性の破綻にとどまらず破壊性の要素も加味されているため，強固な支持性再建が求められ instrumentation が重要な役割を果たす．

外科治療では，病変の自然経過を念頭に置き疾患重症度を加味して手術術式を選択することが必要で，重症病型においては責任高位以外の今後進行が予測される病変も予防的な意味を含めて固定術の範囲に含めることが推奨される．骨粗鬆症も留意すべ



a　　b

図 10-2-19　関節リウマチによる頚椎病変(AAS＋VS＋SS 例)
a：単純 X 線側面像　b：MRI T 2 強調矢状断像

き点で，instrumentation が進歩したとはいえ過大な期待はできない．また，脊髄症状がかなり進行した段階での手術成績は不良であり，早期手術が推奨されてきているが，脊髄症状出現の予測やその発症予防の意味での手術までは確立されておらず，今後の課題である．

3．強直性脊椎炎

強直性脊椎炎 ankylosing spondylitis(AS)は，主に仙腸関節・脊椎がおかされる慢性全身性炎症疾患である．*リウマトイド因子陰性脊椎関節症* seronegative spondyloarthropathy の疾患概念ができ，その代表疾患に位置づけられる．病変の主体は付着部炎で，脊椎では椎間板線維輪，前・後縦靱帯と椎骨縁に炎症性変化を生じ，骨化に至る．

脊椎 X 線像では椎体縁が直線化し椎体方形化(squaring)した後，線維輪の表層が徐々に骨化し上下の椎体をつなぎ(*靱帯骨棘形成* syndesmophyte)，さらに椎間関節の強直化も来し，完全な脊柱癒合(*竹状脊柱* bamboo spine)となる．

4．その他の非特異性脊椎炎

その他の脊椎炎として，前述のリウマトイド因子陰性脊椎関節症に含まれる疾患があげられ，これには反応性関節炎(Reiter 症候群)，若年性脊椎関節炎，乾癬性関節炎，炎症性腸炎(Crohn 病，潰瘍性大腸炎，Whipple 病)に伴う関節炎が含まれる．

掌蹠膿疱症も脊椎病変がみられることで知られている．X 線で，椎体終板の破壊と骨吸収像，硬化像の混在することが多く，骨シンチグラフィーでは胸鎖関節部や脊椎の他部位にも集積を認めることが多い．予後良好で，対症的な消炎鎮痛剤の投与でよい．

(小田剛紀，米延策雄)

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Usefulness of neurological examination for diagnosis of the affected level in patients with cervical compressive myelopathy: prospective comparative study with radiological evaluation

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Object. Although neurological examination is the key step to reaching a correct diagnosis of cervical compressive myelopathy (CCM), the accuracy of diagnosis of the affected spinal level for CCM has not yet been tested.

Methods. The authors conducted a prospective study to elucidate how accurately the affected intervertebral level can be determined and decompressed based on neurological examination. Fifty patients who underwent successful decompressive surgery for cervical myelopathy caused by single-level disc herniation or spondylosis were included in this study (38 men and 12 women, mean age 60 years). Three board-certified spine surgeons participated in establishing the neurological diagnoses. One of the three surgeons made a diagnosis of CCM, and the other two conducted the neurological examination including deep tendon reflex, pinprick response, muscle weakness, and numbness in the hand only, knowing that the patient had CCM, and established the neurological-level diagnosis. A single intervertebral level responsible for patient's symptoms was determined concordantly based on magnetic resonance imaging and myelography findings by two spine surgeons, and this served as the standard. Agreement between neurological and neuroimaging/radiological level diagnoses was determined. The rate of agreement between neurological and neuroimaging diagnosis was 66%. Among the neurological tests, patient-perceived location of numbness in the hands was the most useful for establishing the affected level. For the other three tests the agreement rate was lower than 50% and thus each individual test may not be reliable for diagnosing the affected level.

Conclusions. The results of this study suggested that neurological examination in patients with CCM is moderately accurate and reliable for determining the neurological level of disease.

KEY WORDS • **cervical compressive myelopathy** • **neurological examination** • **diagnosis**

DESPITE recent advances in diagnostic imaging modalities, neurological examination remains the most important and indispensable aspect of diagnosing CCM. When considering surgical treatments for this disease, it is necessary to locate the spinal level that is responsible for neurological deficits and that should be decompressed. There are numerous published reports involving the neurological diagnosis of the responsible spinal level in cases of cervical radiculopathy.[4,7,11] In textbooks including that written by Hoppenfeld[4] authors describe in detail the neurological level diagnosis for cervical radiculopathy. On the other hand, there are only a few reports concerning diagnosis of the responsible level for cervical myelopathy.[2,5,6,8] The difficulty of determining the responsible level for CCM may be attributable to discrepancy between an affected intervertebral level and an affected segment of the spinal cord.[1,5,9] For example, although a herniated C5–6 disc, when located laterally, usually compresses the C-6 nerve root, it does not always compress the C-6 segment of the spinal cord, when located medially. This discrepancy may be due to the lag that develops between the spinal cord segments and the spinal vertebrae during growth, and edema that spreads to upper and/or lower levels from the site of spinal cord compression. Hirabayashi, et al.,[2] reported that the myelomere associated with motor function is shifted one segment cranially and that associated with sensory function is shifted 1.5 to two segments cranially with respect to the intervertebral level. For example, the motor myelomere at C-6 and the sensory myelomere at C-6 or C-7 are primarily disturbed by a compressive lesion at C4–5.

In 1983, Kokubun[5] reviewed the available data concerning determination of the responsible spinal level based on neurological findings and proposed the use of several neurological findings specific to compressive

Abbreviations used in this paper: CCM = cervical compressive myelopathy; CT = computerized tomography; MMT = Manual Muscle Test.

lesions at each level for the diagnosis for the responsible level. Similarly, Hirabayashi, et al.,[2] proposed various indicators of the responsible level based on the pattern of changes in the following: reflexes, sensory functions, muscle strength, and extent of numbness in the hand. Thus, they provided the neuroanatomical basis for the diagnosis of the responsible spinal level. All of these reports, however, were based on retrospective surveys. No prospective study has been conducted to determine to what extent accurate neurological diagnosis of the responsible level is possible when using such indicators.

The present study was undertaken prospectively to compare neurological examination findings with those of the diagnostic imaging in patients with CCM and to evaluate the usefulness of determining the responsible level based on neurological findings.

Clinical Material and Methods

Patient Population

The patients in the study had undergone surgery for cervical myelopathy due to single-level cervical spondylosis or disc herniation between 2000 and 2002 at our institute. A diagnosis of myelopathy was established based on the presence of hyperreflexia including positive Hoffmann sign and upper- and/or lower-extremity sensory disturbance as well as obvious MR imaging–documented cervical spinal cord compression. Patients with a history of surgery, those with ossification of posterior longitudinal ligament, and those with marked nerve root symptoms (positive Spurling sign) were excluded from this study. Initially, 56 patients met the aforementioned criteria; however, six were excluded because a responsible level could not be determined on neuroimaging. Thus, 50 patients (38 men and 12 women, mean age 60 years [range 30–80 years]) were finally included in this study. The preoperative diagnosis was disc herniation in eight patients and spondylotic myelopathy in 42 patients.

Neurological Examination

Three board-certified orthopedic surgeons with more than 10 years of experience in spinal surgery served as the examiners. One examiner made the diagnosis of CCM and determined the indication of surgical treatments at the outpatient clinic. The other two examiners independently determined the responsible level by undertaking a neurological examination—they were not provided prior clinical information other than the diagnosis of CCM. Thus, the responsible vertebral level was determined in duplicate for each patient (100 reports for 50 cases).

Of the various neurological tests, deep tendon reflexes, pinprick sensation, manual muscle strength, and patient-perceived area of numbness were chosen for diagnosis because they had been reported to be useful for this purpose.[2,5,6] Biceps and triceps tendon reflexes were rated as exaggerated, normal, or diminished. An exaggerated reflex was a long tract sign indicating that a compressive lesion was located at a rostral segment, and a diminished reflex was a segmental sign indicating that the lesion was located at the segment associated with the reflex.

In pinprick sensation, the uppermost impaired level was recorded according to the dermatome proposed by Nozaki.[7] Hand numbness was determined by asking patients the part of the hand in which they most strongly felt numbness. Neurological signs found in the more severely impaired side were used for diagnosis of the spinal level. The diagnosis was made by referring to the indicators for level-related diagnosis reported previously in our retrospective analysis of 105 cases of single-level disc herniation (Table 1).[6] Although these indicators were used as references, the final level-related diagnosis was determined based on judgments of each examiner. Initially, the responsible level was determined according to each neurological sign—that is, deep tendon reflex, pinprick sensation, MMT, and hand numbness, and then by the overall neurological signs.

The surgical procedure used was an expansive open-door laminoplasty in 40 patients and a single-level anterior fusion in 10. In patients treated using laminoplasty, four intervertebral levels (C3–4 to C6–7) were always decompressed according to the method originally proposed by Hirabayashi, et al.[3] Neither internal fixation nor foraminotomy was conducted in any case.

Because neurological symptom improvement was obtained in all 50 cases, the preoperative diagnosis of CCM was confirmed. The mean Japanese Orthopaedic Association score for cervical myelopathy was 10.0 ± 2.7 before surgery, whereas at the final follow-up examination (mean follow-up period 2.3 years, range 1.6–3 years) it was 13.9 ± 2.2. The improvement in Japanese Orthopaedic Association scores ranged from one to nine (mean four).

Diagnostic imaging included MR imaging and post–myelography CT scanning in all patients. The responsible level was determined as the maximally compressed areas on MR images, myelograms, and post–myelography CT scans, and as a high intensity mass within the spinal cord on T_2-weighted MR images. The presence or absence of foraminal stenosis at the maximally compressed level was also determined. The images were evaluated by two experienced board-certified orthopedic surgeons who were blinded to any other information on the patients, and the responsible level was determined concordantly by the two examiners. If they could not reach agreement with regard to the responsible myelography- or MR imaging–documented level in a given patient, the case was excluded from the analysis. Thus, data obtained in six patients in whom agreement between the two examiners was not obtained were excluded from the final analysis. The agreement between the imaging- and neurological examination–based diagnoses was then analyzed and the agreement rate calculated as the number of neurological diagnoses correlated with radiological diagnoses divided by the total number of the neurological diagnoses (that is, 100 diagnoses).

Results

The responsible imaging-documented levels were C3–4 in 14 patients, C4–5 in 16, C5–6 in 17, and C6–7 in three. Radiological/neuroimaging findings in each patient are tabulated in Table 2. In 48 patients (96%) there was a high-intensity area of the spinal cord on T_2-weighted sagittal MR images. In two patients two-level high-intensity lesions were demonstrated. In these 48 patients, the levels of the high-intensity areas corresponded to the levels where the spinal cord was maximally compressed. In the two patients

TABLE 1

*Neurological criteria for diagnosis of the vertebral level responsible for CCM**

Level	Deep Tendon Reflex	Pinprick†	MMT‡	Hand Numbness§
C3–4	BTR exaggerated TTR exaggerated	C-5	deltoid	whole hand
C4–5	BTR diminished TTR normal or exaggerated	C-6	biceps	radial side
C5–6	BTR normal TTR diminished	C-7	triceps	ulnar side
C6–7	BTR normal TTR normal	C-8	wrist extensor intrinsic muscles	none ulnar side of forearm

* Adapted from Kokubun. Abbreviations: BTR = biceps tendon reflex; TTR = triceps tendon reflex.

† Indicates the uppermost impaired level described according to Nozaki dermatome.

‡ Indicates the uppermost weakened muscle.

§ The area in the hand where patients feel numbness most strongly.

without a high-intensity area and in the two patients with two-level high-intensity lesions, the responsible level was determined based on the severity of spinal cord compression on MR imaging and myelography. Foraminal stenosis was noted in eight patients in whom the responsible levels were determined by radiological examination, bilaterally in two patients and unilaterally in six.

The agreement rate between neurological and radiological examinations was 62% for extent of numbness of the hand, 40% for sensory disturbance, 36% for deep tendon reflexes, and 19% for muscle weakness. The agreement rate was 66% for overall neurological signs (Fig. 1 *upper left*) and that for overall neurological signs was 75 and 64% in the eight patients with and without foraminal stenosis (statistically not significant).

The agreement rate of each neurological sign in the patients in whom the overall neurological and radiological diagnoses agreed was 52% for deep tendon reflexes, 62% for sensory disturbance, 23% for muscle weakness, and 89% for hand numbness (Fig. 1 *upper right*). The incidence of cases in which agreement was seen for all the neurological signs was only 6.1%. When analyzed by age group, the agreement rate was highest in patients 30 to 39 years (83%) and it decreased with advancing age (Fig. 1 *lower left*).

When the agreement between the overall neurological and radiological diagnoses was analyzed by level, the rate was highest at the C3–4 level (75%) and lowest at the C4–5 level (56%) (Fig. 1 *lower right*).

The interexaminer agreement rate between two of the three examiners was 43, 68, and 78% for each of the three examiners, respectively (mean 63%). Thus, the consistency among the three examiners was considered to be fair to moderate.

Discussion

In the present report, we undertook a prospective study to determine the agreement between neurological examination and radiological examination for establishing the responsible intervertebral level of CCM.

In previous reports, a particular spinal level was deemed

TABLE 2

Summary of radiological findings in 50 patients with CCM

	Cervical Level			
		MRI		
Case No.	Blockage on Myelogram	High Signal Intensity	Most Compressive level	Responsible Level*
1	none	C3–4	C3–4	C3–4
2	C3–4	C3–4	C3–4	C3–4
3	C3–4	C3–4	C3–4	C3–4
4	C3–4	C3–4	C3–4	C3–4
5	none	none	C3–4	C3–4
6	C3–4	C3–6	C3–4	C3–4
7	C3–6	C3–4	C3–4	C3–4
8	none	C3–4	C3–4	C3–4
9	C3–4	C3–4	C3–4	C3–4
10	C3–4	C3–4	C3–4	C3–4
11	C3–4	C3–4	C3–4	C3–4
12	C3–4	C3–4	C3–4	C3–4
13	C3–4	C3–4	C3–4	C3–4
14	C3–4	C3–4	C3–4	C3–4
15	C4–5	C4–5	C4–5	C4–5
16	C4–5	C4–5	C4–5	C4–5
17	C4–5	C4–5	C4–5	C4–5
18	C4–5	C4–5	C4–5	C4–5
19	C4–5	C4–5	C4–5	C4–5
20	C3–4	C4–5	C4–5	C4–5
21	C4–5	C4–5	C4–5	C4–5
22	C4–5	C4–5	C4–5	C4–5
23	C4–5	C4–5	C4–5	C4–5
24	C4–5	C4–5	C4–5	C4–5
25	C4–5	C4–5	C4–5	C4–5
26	C4–5	C4–5	C4–5	C4–5
27	C4–5	C4–5	C4–5	C4–5
28	C4–5	C4–5	C4–5	C4–5
29	C5–6	C5–6	C5–6	C5–6
30	C5–6	C5–6	C5–6	C5–6
31	C5–6	C5–6	C5–6	C5–6
32	C5–6	C5–6	C5–6	C5–6
33	C5–6	C5–6	C5–6	C5–6
34	C5–6	C5–6	C5–6	C5–6
35	C5–6	C5–6	C5–6	C5–6
36	none	none	C5–6	C5–6
37	C5–6	C5–6	C5–6	C5–6
38	C5–6	C5–6	C5–6	C5–6
39	C5–6	C5–6	C5–6	C5–6
40	none	C5–6	C5–6	C5–6
41	C5–6	C5–6	C5–6	C5–6
42	C5–6	C5–6	C5–6	C5–6
43	C4–5	C5–6	C5–6	C5–6
44	C5–6	C5–6	C5–6	C5–6
45	C5–6	C5–6	C5–6	C5–6
46	C5–6	C5–6	C5–6	C5–6
47	C5–6	C5–6	C5–6	C5–6
48	C6–7	C6–7	C6–7	C6–7
49	C6–7	C6–7	C6–7	C6–7
50	C5–7	C5–7	C6–7	C6–7

* Responsible level determined by radiological examination.

the responsible level if ipsilateral anterior decompression resulted in alleviation of symptoms.[3,5] This successful surgical result served as the gold standard for diagnosis of the responsible level. In recent years, however, posterior approaches have been used more often than anterior approaches when treating a single-level compressive lesion associated with developmental canal stenosis. In the patients presented in this paper, only 20% underwent anteri-

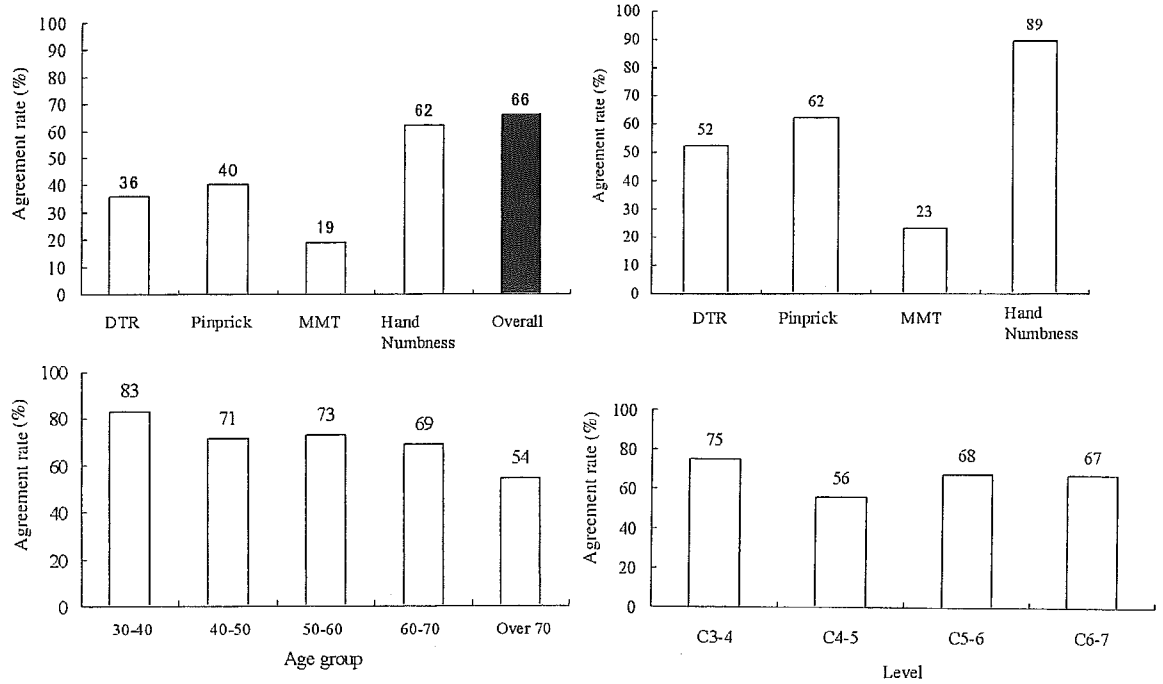

FIG. 1. Bar graphs. *Upper Left:* Agreement of level diagnosis stratified by neurological sign and overall neurological examination with radiological level diagnosis. Hand numbness was associated with the highest agreement rate, whereas deep tendon reflexes, pinprick sensation, and muscle strength were associated with agreement rates lower than 50%. *Upper Right:* Agreement rate of each neurological sign in patients in whom overall neurological level diagnosis agreed with radiological level diagnosis. Hand numbness was associated with the highest agreement rate. *Lower Left:* Agreement rate of neurological and radiological level diagnoses stratified by age group. The agreement rate decreased as age increased. *Lower Right:* Agreement rate of neurological and radiological level diagnoses stratified by intervertebral level. The rate was highest in patients with a C3–4 compressive lesion and lowest at C4–5. DTR = deep tendon reflex.

or fusion. Because the level to be decompressed in patients with CCM is usually determined by diagnostic imaging, we believe that the use of the radiological findings as the standard has clinical relevance. Radiological findings were evaluated by two experienced board-certified orthopedic surgeons in a concordant fashion, and if they disagreed on the responsible level in any patient, the case was strictly excluded from the study. Therefore, the results of radiological evaluation can be considered to be reliable enough to serve as the standard for the comparison.

On MR imaging, the presence or absence of high signal intensity of the spinal cord and foraminal stenosis was evaluated. A high signal intensity lesion was present in most cases, and the level of such a lesion was deemed responsible for symptoms, whereas the presence of foraminal stenosis did not have an impact on the diagnosis established by neurological examination. This may be partly because patients with positive Spurling sign (that is, those with symptomatic radiculopathy) were excluded from the study to render neurological examination–based diagnosis simpler.

The overall agreement between the two modes of diagnosing the CCM-related level was 66% in this study. Although this incidence may not be sufficiently high, it does suggest that neurological examination can provide reference information for determining the responsible level preoperatively in two thirds of the cases. When the agreement rate was analyzed according to each neurological sign, it was highest for hand numbness and particularly low for muscle weakness. The value for abnormal reflexes and sensory disturbance was less than 50%. These results indicated that the patterns of reduced muscle strength, abnormal reflexes, and sensory disturbance are unlikely to serve as useful indicators of the responsible level when used individually. The percentage of patients in whom agreement was seen for all the neurological signs was only 6.1% (Fig. 2). These results suggested that, when determining the responsible level neurologically, it is advisable to make a general evaluation of all neurological signs, giving primary importance to the area of numbness in the hand. It is not known why hand numbness was associated with the most diagnostic value. Hirabayashi, et al.,[2,3] speculated that numbness in the hand may reflect damages of the spinal segment and long tract. Therefore, patients with a C3–4 compressive lesion tend to have numbness in the more extended area, such as the entire hand than those with a lesion at more caudal levels. The low agreement rate of muscle strength can be attributed, partly, to dual or triple innervation of tested muscles. For example, the biceps muscle is innervated by both C-5 and C-6 and the triceps by C-6, C-7, and C-8.

The agreement rate was highest in patients with C3–4 lesions. This is probably because the incidence of specific neurological symptoms (for example, numbness of all fingers, reduction in deltoid muscle strength, and reduction of the biceps tendon reflex) is high in cases of C3–4 compression.[2,5,6] When the agreement rate was analyzed in relation to age, it was found to decrease as age increased. This may be attributable to the following factors: 1) reflexes and muscle strength tend to decrease with advanc-

Neurological diagnosis of the affected spinal level

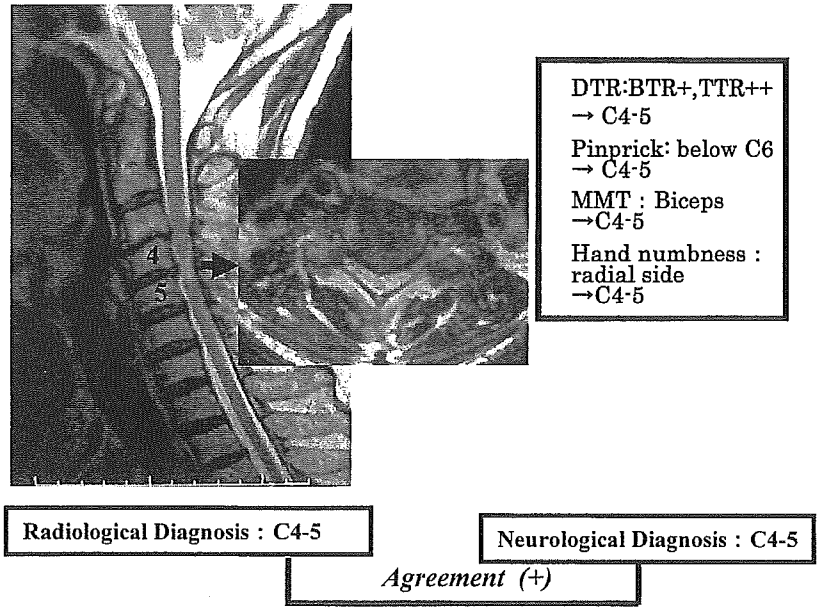

FIG. 2. Images obtained in a 67-year-old man with a C4–5 compressive lesion in whom agreement between all neurological and radiological examinations was obtained. He had normal biceps tendon reflex (BTR) and exaggerated triceps tendon reflex (TTR), sensory disturbance below C-6, muscle weakness below biceps, and numbness in the radial side of the hands. Therefore, in this patient, neurological-level diagnosis by all neurological signs agreed with radiological level diagnosis.

ing age, which may make neurological examination difficult; and 2) in elderly patients, cervical myelopathy is often complicated by other diseases that cause neuropathy such as diabetes mellitus.

A posterior approach is often used for compressive myelopathy. The preoperative importance of diagnosing the responsible level by neurological examination may be relatively low when a posterior approach is used because decompression is conducted at multiple levels. In recent years, however, posterior-approach minimally invasive surgery (for example, a microendoscopic approach), has also been attempted, and the number of reports on posterior-approach decompression of limited specific spinal levels is also increasing.[10,12] We therefore believe that the importance of conducting preoperative neurological examination to determine the affected level will never decrease.

Conclusions

We prospectively analyzed the consistency between neurological examination and diagnostic imaging for determining the level of CCM. The overall agreement rate was 66%. This result suggests that neurological examination may serve as a moderately reliable preoperative diagnosis of the responsible level in cases of compressive myelopathy. Neurological-level diagnosis can detect the responsible level in younger patients and in those with a C3–4 compressive lesion more accurately.

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ORIGINAL ARTICLE

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Bone resorption of the facet joint in rheumatoid arthritis as a predictor of lower cervical myelopathy

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Abstract The purpose of the present study was to identify the risk factors to predict instability of the subaxial cervical spine and cervical myelopathy based on plain radiographs. The study was performed on 99 patients with mutilating rheumatoid arthritis (RA). From plain lateral radiographs of the cervical spine over time, rheumatoid cervical spine lesions were investigated and evaluation was made on the possibility to develop cervical myelopathy. The incidence of subaxial cervical spine lesions in the patients with mutilating RA was as high as 98%. In particular, resorption of the superior facet suggests high risk to develop cervical myelopathy. The presence of spinous process erosion is also likely to reveal such a possibility. There was no statistically significant difference in the anteroposterior diameter of cervical spinal canal between the cases with cervical myelopathy and those without it. Resorption of the superior facet is the most important factor for the development of cervical myelopathy. In the cases with rheumatoid cervical spine lesions, it is necessary to take special notice of the superior facet.

Key words Cervical myelopathy · Facet joint · Mutilating rheumatoid arthritis (RA)· Subaxial subluxation (SAS)

Introduction

In patients with rheumatoid arthritis (RA), cervical spine lesions are most frequently seen not only in the atlantoaxial joint but also in the subaxial cervical spine. With the progression of subaxial cervical spine lesions, there is a high possibility of developing cervical myelopathy due to instability of the cervical spine or to soft tissues such as rheumatoid granulation. Also, there are cases where the whole cervical spine turns to a state of fusion and stability, thereby not developing cervical myelopathy. Thus, it is difficult to predict the development of cervical myelopathy based on subaxial cervical spine lesions. In this respect, the purpose of the present study is to focus attention on those cases of mutilating RA with a high risk of developing cervical myelopathy, and to identify the risk factors in order to predict instability of the subaxial cervical spine and signs of cervical myelopathy, based on plain radiographs which can be assessed in ordinary outpatient clinics.

Patients and methods

The study was performed on 99 patients with mutilating rheumatoid arthritis (RA) (5 male and 94 female patients) who did not have cervical myelopathy at the first visit to our hospital. For 19 patients who had been operated on the cervical spine, the study was performed on the conditions before the time of operation. The mean age of the patients at the time of study was 64.5 years old (range: 48–83 years). The average duration of RA was 17.4 years (range: 2.0–33.7 years) at the first visit and 26.4 years (range: 6.3–51.8 years) at the time of study. The average duration of radiographic follow-up was 9.0 years (range: 2.0–22.5 years). According to the classification of Steinbrocker, all cases were in Stage III or IV. There were 23 cases in Class 2, 56 cases in Class 3, and 20 cases in Class 4. According to the definition of Murasawa et al.,[1] mutilating RA was defined as the case where radiographic bone resorption of Larsen grade 5 was found in more than three finger or toe joints and more than two major joints.

Plain lateral radiographs of the cervical spine were taken in full flexion and full extension at a 1-year interval. Patients were asked to flex and extend their necks until discomfort or stiffness inhibited further movement. The radiographs were read by two of the authors without knowledge of the

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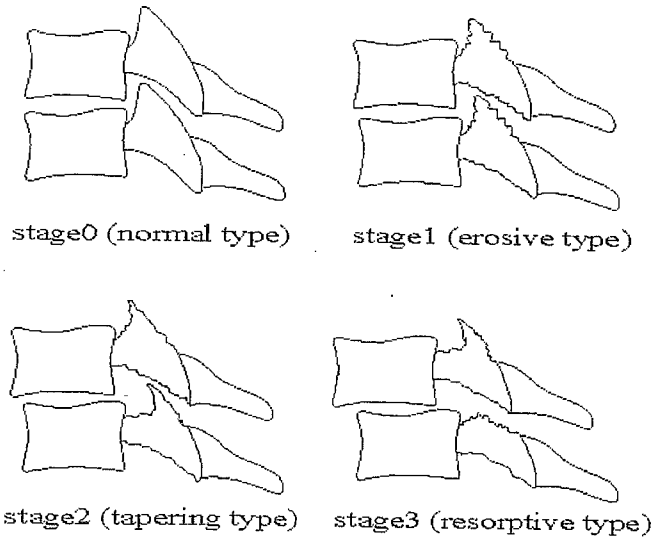

Fig. 1. Classification of the facet joint

clinical or serological data. The radiological criteria used in this study were subaxial subluxation (SAS) with 2mm or more anteroposterior slip from the line drawn on the lower posterior vertebral margin, facet joint erosion, endplate erosion, spinous process erosion, narrow disc space without osteophytosis, and immobility of the cervical spine associated with spontaneous vertebral fusion or facet fusion, and these were considered as rheumatoid subaxial cervical spine lesions previously reported by Sharp et al.[2] and other researchers. We classified rheumatoid lesions of the facet joint into four stages according to the extent of erosion and its resultant shape. In stage 0 (normal type), the facet joint has a normal shape without noticeable erosion. In stage 1 (erosive type), the facet joint has a slight or medium macroscopic erosive change. In stage 2 (tapering type), the facet joint has a severe destructive change as the superior facet looks like a tapering pencil. At stage 3 (resorptive type), there is severe involvement of the facet joint. Its normal superior facet has disappeared and the inclination angle of the facet joint (the angle made by the line drawn along the joint surface of the inferior joint process and the line drawn on the posterior vertebral margin in the lateral view) has increased (Fig. 1). Also, the degree of SAS and the space available for the spinal cord (SAC) on the narrowest level in full flexion or extension were measured. The anteroposterior diameter of the cervical spinal canal was directly measured from the cranioanterior edge of C5 lamina to the posterior margin of C5 vertebral body. It was confirmed whether the patients had used steroids. Cervical myelopathy was determined through a careful neurological examination. However, on these patients this was always difficult. Thus, we evaluated it by mainly checking hyperreflexia, dysesthesia, sensory deficits, and activities of daily living. Ranawat's classification[3] was used for the evaluation of cervical myelopathy, and the level of responsibility for cervical myelopathy was determined according to neurological and radiographic (including magnetic resonance imaging) findings. For statistical analysis, the χ^2 test, Kruskal–Wallis test, and Mann–Whitney *U*-test were performed using JMP 5.1. (SAS Institute, Cary, NC, USA).

Table 1. Incidence of subaxial cervical spine lesions classified by items

	n (%)
Facet joint erosion	96 (97)
Narrow disc space	89 (90)
Endplate erosion	87 (88)
SAS	70 (71)
Spinous process erosion	69 (70)
Immobility of cervical spine	31 (31)

SAS, subaxial subluxation

Table 2. Relationship between plain radiographic findings of subaxial cervical spine lesions and cervical myelopathy

	P value
Classified facet joint erosion	<0.001
Narrow disc space	NS
Endplate erosion	NS
SAS	NS
Spinous process erosion	<0.05
Immobility of cervical spine	NS

NS, not statistically significant

Results

At the initial point of this study, 85% of these 99 patients already had rheumatoid subaxial cervical spine lesions on plain lateral radiographs. At the time of study, the incidence of rheumatoid subaxial cervical spine lesions was 98%. The incidence of facet joint erosion was 97%. When classified by items, the stages of the facet joint were classified into: stage 0 (normal type) 3%, stage 1 (erosive type) 71%, stage 2 (tapering type) 15%, and stage 3 (resorptive type) 11%. Each stage reflected increasing involvement and rheumatoid destruction of the facet joint. Narrow disc space without osteophytosis was found in 90% of the cases, endplate erosion in 88%, SAS in 71%, spinous process erosion in 70%, and immobility of the cervical spine associated with spontaneous vertebral fusion or facet fusion in 31% of the cases (Table 1). Subaxial cervical spine lesions were found at high frequency in C5 and C6. Eighty-seven cases had used steroids. The cases of cervical myelopathy of II or more in Ranawat's classification were seen in 29 of 99 cases. The level of responsibility for cervical myelopathy was seen at the atlantoaxial joint in eight cases, and the subaxial cervical spine in 21 cases. In plain radiographic findings of the subaxial cervical spine, a statistically significant difference from cervical myelopathy was found in SAC, classified facet joint erosion, and spinous process erosion. No significant difference was noted in SAS, endplate erosion, immobility of the cervical spine, and narrow disc space without osteophytosis (Table 2). Also, no significant association was found between the use of steroids and subaxial cervical

Table 3. Stage of the facet joint and cervical myelopathy

	Ranawat I	Ranawat II	Ranawat IIIA	Ranawat IIIB
Normal type, *n*	2	1	0	0
Erosive type, *n*	59	2	9	0
Tapering type, *n*	7	0	5	3
Resorptive type, *n*	2	3	2	4

n, number of patients

Table 4. Spinous process erosion and cervical myelopathy

	Ranawat I	Ranawat II	Ranawat IIIA	Ranawat IIIB
Yes, *n*	42	5	15	7
No, *n*	28	1	1	0

n, number of patients

myelopathy. Among the cases with facet joint erosion, cervical myelopathy was detected in 11 of 70 cases in stage 1 (erosive type), 8 of 15 cases in stage 2 (tapering type), and 9 of 11 cases in stage 3 (resorptive type). Resorptive image of the superior facet suggests a particularly high risk of developing cervical myelopathy ($P < 0.001$) (Table 3). In the cases with spinous process erosion, cervical myelopathy was found in 27 of 69 patients, and this suggested a high possibility of developing cervical myelopathy if spinous process erosion was present ($P < 0.05$) (Table 4). Subaxial subluxation became more severe as the stage of the facet joint moved from stage 0 (normal type) to stage 1 (erosive type), stage 2 (tapering type), and stage 3 (resorptive type). It was 0.5 mm on average in stage 0, 1.5 mm in stage 1, 3.3 mm in stage 2, and 7 mm in stage 3 ($P < 0.001$). Subaxial subluxation became more severe when spinous process erosion was present. It was 3.1 mm on average in the patients with spinous process erosion ($P < 0.001$) (Fig. 2). In SAC, a statistically significant difference was found depending on whether or not cervical myelopathy was present ($P < 0.0001$). Space available for the spinal cord was 11.5 ± 2.1 mm on average in the cases with cervical myelopathy and 14.2 ± 1.8 mm on the cases without cervical myelopathy (Fig. 3). On the other hand, no significant difference was noted in the anteroposterior diameter of the cervical spinal canal depending on whether or not cervical myelopathy was present (Fig. 4). However, in the patients with mutilating RA who developed cervical myelopathy, cervical myelopathy occurred even when SAS was mild if the anteroposterior diameter of cervical spinal canal was narrow (Fig. 5).

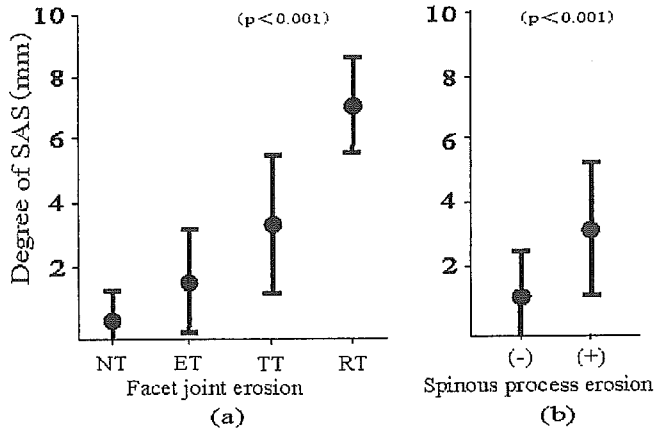

Fig. 2a,b. Plain radiographic findings and the degree of subaxial subluxation (*SAS*). **a** SAS becomes more severe as the stage of the facet joint is turned to normal type (*NT*), erosive type (*ET*), tapering type (*TT*), and resorptive type (*RT*). **b** SAS becomes more severe when spinous process erosion is present

Case reports

Case 1 (Fig. 6)

Vertebral fusion was found on C5–C6. Erosive change of the facet joint and mild SAS were seen at C4/5. Eight years later, vertebral fusion was found on C3–C4, and SAS advance was noted at C4/5. However, the facet joint of C4/5 maintained its shape and merely showed erosive change. SAS at C4/5 advanced, but remained as mild subluxation.

Case 2 (Fig. 7)

Tapering change of the facet joint and moderate SAS were found at C5/6. Nine years later, tapering change advanced, but remained as tapering type and no progress was seen in SAS.

Case 3 (Fig. 8)

Tapering change was found in the facet joint and SAS was mild at C5/6. Three years later, the superior facet disappeared and the inclination angle of the facet joint increased. Severe SAS was seen and cervical myelopathy developed.

Case 4 (Fig. 9)

Resorption of the facet joint, increased inclination angle of the facet joint, and moderate SAS were seen at C6/7. Two years later, severe SAS and cervical myelopathy developed.

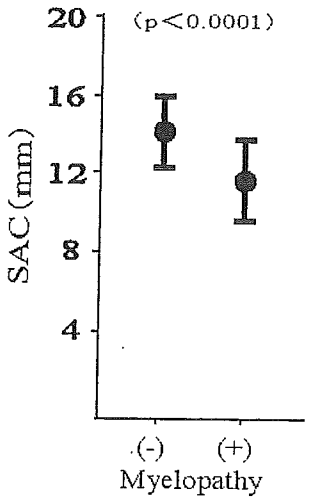

Fig. 3. Relation of cervical myelopathy and space available for the spinal cord (*SAC*). In SAC, a statistically significant difference was found depending on whether or not cervical myelopathy was present

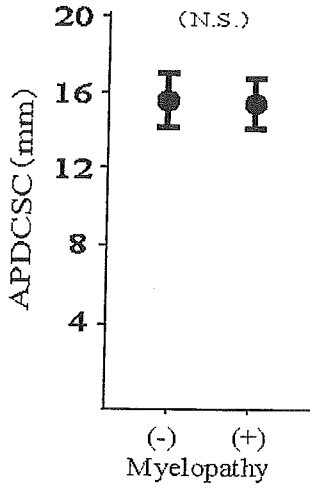

Fig. 4. Relation of cervical myelopathy and the anteroposterior diameter of cervical spinal canal (*APDCSC*). No significant difference was noted in APDCSC depending on whether or not cervical myelopathy was present

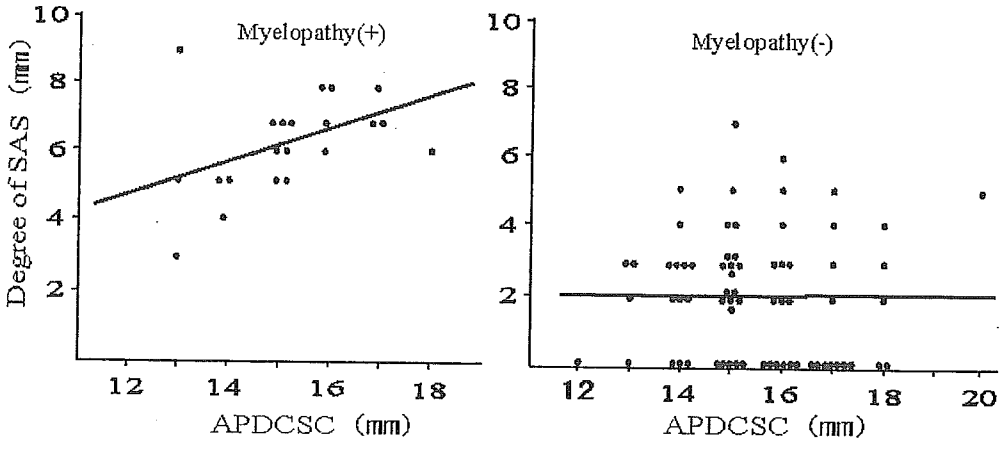

Fig. 5. In the patients with mutilating rheumatoid arthritis who develop cervical myelopathy, cervical myelopathy develops despite a mild degree of subaxial subluxation (*SAS*) if the anteroposterior diameter of cervical spinal canal (*APDCSC*) is narrow

Discussion

According to the report by Da Silva et al.,[4] who described the results of a retrospective study on 609 patients with RA, 242 patients had undergone the operation on joints associated with RA, and the cumulative ratio of surgical operation for 30 years was 33.7% ± 3.8%, while the cervical spine operation was found only in two cases, and the cumulative incidence was 0.4% ± 0.4%. This may mean that there was less possibility to cause clinical problems even when the cervical spine lesion was detected on plain radiographs of the patients with RA. However, patients with mutilating RA often require the cervical spine operation. Laiho et al.[5] reported that 26% of patients with arthritis mutilans hand deformity had been operated on their cervical spine. Nineteen patients (19%) in the present study had been operated on the cervical spine. If cervical myelopathy developed, the prognosis was poor. There are reports that one half of the patients died within 1 year after the diagnosis of myelopathy[6] or that, among 21 patients who did not undergo operation despite the presence of cervical myelopathy, all patients became bedridden within 3 years and died within 7 years after the diagnosis.[7] When an operation was performed to treat cervical myelopathy, activities of daily living could be maintained or improved at least for a certain period.[8] This suggests that it is important to take adequate action at an earlier stage.

Regarding the risk factor to predict cervical myelopathy based on plain radiographic images, there is no satisfactory predictor other than SAC[9-11] and rapid and extensive progress of peripheral articular lesions.[12] Up to now, there have been reports describing that rheumatoid lesions in posterior regions such as the facet joint, the spinous process, etc., are closely related to anterior slip.[13-16] Based on the results of a biomechanical study, White and Panjabi[17] reported that anterior instability appears as the result of the destruction of posterior elements of the spine around the facet joint. Kuwahara et al.[18] reported that pathological findings of the cervical spine, which were most frequently found at autopsy in patients with RA, were synovitis in the facet joints, and that RA granulation was found at high

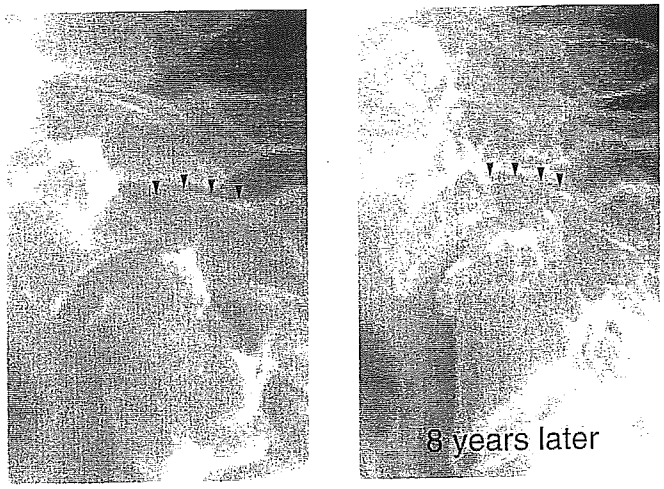

Fig. 6. Case 1. A 63-year-old woman; duration of disease 22 years: stage 1 (erosive type) (*arrowheads*)

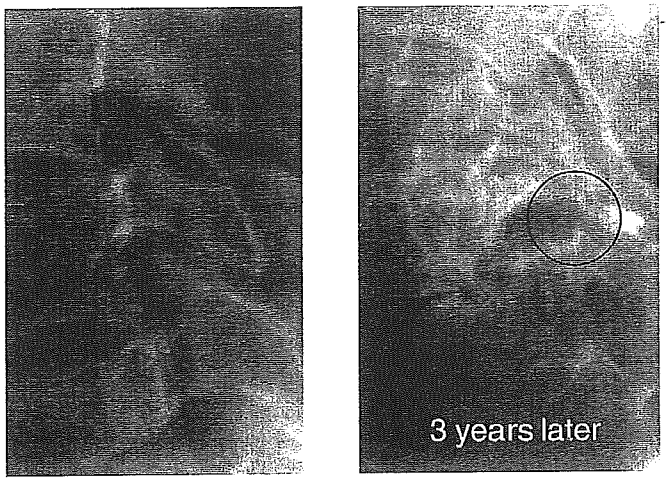

Fig. 8. Case 3. A 73-year-old woman; duration of disease 15 years; stage 3 (resorptive type) (*area in circle*)

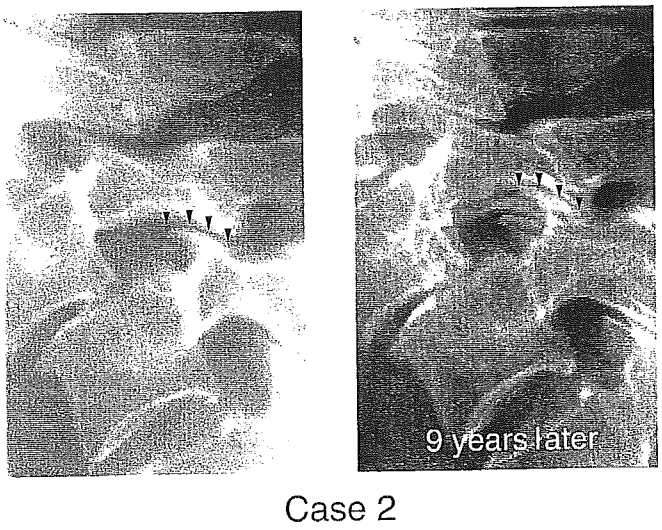

Fig. 7. Case 2. A 63-year-old woman; duration of disease 17 years; stage 2 (tapering type) (*arrowheads*)

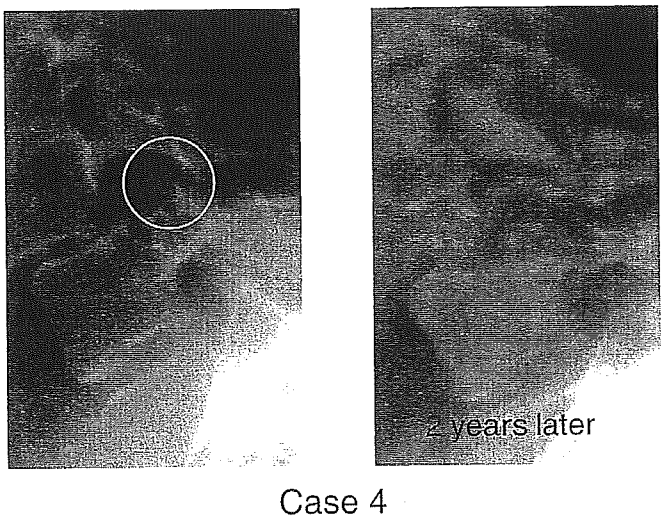

Fig. 9. Case 4. A 50-year-old woman; duration of disease 15 years; stage 3 (resorptive type) (*area in circle*)

frequency in the facet joint or posterior elements such as bone marrow of the spinous process or the attaching region of ligaments. In the results of our present study, facet joint erosion was most frequently seen in the rheumatoid subaxial cervical spine. Therefore, we focused on the facet joint to delineate dynamic instability caused by subaxial cervical spine lesions. There is a report that anterior slip of the affected segment becomes severe when the inclination angle of the facet joint becomes greater.[13] However, this angle needs a measurement by a level because normal values are different. So we think the superior facet is a useful viewpoint to predict marked cervical instability by daily visitor medical examinations. If there is erosive change of the superior facet as seen in the upper portion of Fig. 10, mild SAS occurs but this does not become severe. If there is tapering of the superior facet as seen in the middle portion of Fig. 10, moderate SAS occurs but also does not become severe. If the superior facet is resorbed as seen in the lower portion of Fig. 10, severe SAS occurs and this is more likely to develop cervical myelopathy. In general, in cases of cervical spondylosis a narrow canal is an important factor in the development of cervical myelopathy. This has also been reported regarding RA.[10] However, in the results of the present study there was no statistically significant difference in the anteroposterior diameter of cervical spinal canal in the patients with mutilating RA, depending on whether cervical myelopathy was present. In the subaxial cervical spine of the patients with mutilating RA, a narrow canal is not an important factor in the development of cervical myelopathy. On the other hand, a narrow SAC is a risk factor connected directly with cervical myelopathy. Severe SAS that decreases SAC is closely related to resorptive change

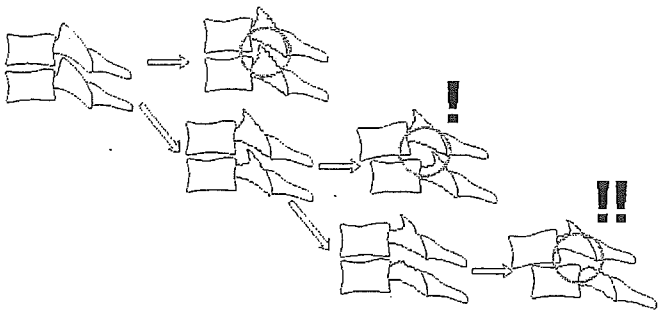

Fig. 10. Facet joint erosion and the progress of subaxial subluxation (*SAS*). As the facet joint is resorbed, anterior instability of the cervical spine increases, and cervical myelopathy develops rapidly

of the facet joint, tapering change of the facet joint, or spinous process erosion, and these may be important findings in predicting cervical myelopathy.

As causes of spinal cord compression in the subaxial cervical spine of the patients with RA, not only a bone factor associated with SAS but also rheumatoid granulation tissues or formation of constricting band on the dura mater have been reported.[19] The immunological process as well as the mechanical process due to instability may cause soft tissue proliferation and adhesion at the site of facet resorption and spinous process erosion. These are not identifiable from plain radiographs, and this suggests that magnetic resonance imaging is necessary in routine medical practice.

In summary, among rheumatoid subaxial cervical spine lesions, facet joint erosion was classified into four types depending on the morphological features of the facet joint seen on plain lateral radiographs. In patients with mutilating RA, there is a high risk for the development of cervical myelopathy if there is resorptive change and tapering change in the cervical facet joint, and it is necessary to take special note of the facet joint. Spinous process erosion is also a risk factor in the prediction of cervical myelopathy. In patients with mutilating RA, no significant difference was noted in the anteroposterior diameter of the cervical spinal canal between patients with cervical myelopathy and those without it. Resorption of the facet joint is the most important factor for the development of cervical myelopathy. In the subaxial cervical spine in those patients with mutilating RA, it is necessary to take special note of the facet joint.

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Ⅰ.脊髄手術への応用

頚椎，頚胸椎疾患に対するコンピューター支援手術

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Key words：cervical spine, computer-assisted surgery

はじめに

近年，サージカルナビゲーションシステムの発達に伴い，脊椎手術においてもコンピューター支援手術の報告が散見されるようになった。コンピューター支援手術の脊椎領域への応用としては，神経除圧や腫瘍切除における手術器具の術中三次元位置情報の提供，周囲組織(大血管，椎骨動脈，重要臓器)との関係の描出，脊椎インストゥルメンテーション設置に伴うスクリュー先端位置のリアルタイムイメージングなどが考えられる。

しかし，現状では大部分が脊椎インストゥルメンテーション設置に伴う使用であり，報告例の多くも胸腰椎または腰椎椎弓根スクリュー刺入に関するものである。頚椎，頚胸椎手術においてのサージカルナビゲーション技術の将来性はきわめて大きいと考えられるが，高い精度保証が必要なことからいまだ一般化していない。

われわれは以前より各種の頚椎不安定病変や変形矯正固定に頚椎椎弓根スクリューを応用し，その有用性を報告してきたが，RAや小児などの椎弓根径が小さい例，頚椎変形，椎弓根非対称などの奇形や椎骨動脈片側閉塞例では合併症のリスクが伴うことを報告した[1), 2)]。

そこで，これらハイリスク手術を安全に行うための補助ツールとして，2001年よりナビゲーションシステムを導入し，臨床応用している。また，高精度のリアルタイムナビゲーションを実現するために，既存のナビゲーションシステムを改良した独自の手術器具を開発し，臨床応用してきた[3)]。本稿ではこれらを用いたコンピューター支援による頚椎椎弓根スクリュー固定の実際と臨床例について述べる。

サージカルナビゲーションの基本原理

現在一般的に臨床使用されているナビゲーションシステムは，optical tracking navigation

Computer-assisted surgery for cervical and cervico thoracic spinal disorders

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systemである。術前または術中に取り込んだCTまたは2方向X線イメージを三次元構築し，このデータ(イメージ空間)と実際の術野データ(サージカル空間)を一致させ(照合)，手術器具と患者の位置関係を精度よく表示させるものである。

システムはコンピューター本体と赤外線を感知するCCDカメラよりなり，対象となる脊椎にreference frameを設置し，これを基準点に座標軸を構築する(**図1**)。照合操作では椎骨の4点を照合するpoint registrationと最大30点からなるsurface registrationを順次行う。これによりフーリエの定理を用いた表面形状のマッチングが行われ，表面と奥行の誤差はなくなり，高い精度を維持したナビゲーションが可能になる。さらに手術器具に取り付けたLED(発光ダイオード)より発生する赤外線をCCDカメラで追跡することで，器具先端の三次元位置を計測する。

ナビゲーションシステムを用いた頚椎椎弓根スクリュー固定の実際

● 術前準備

われわれが使用しているナビゲーションシステムはStealth Station (Medtronic Sofamor Danek社製)である。本システムには術前CTデータを取り込み，三次元脊椎モデルをあらかじめ構築するCT-based システムと，術中2方向X線イメージ像を基にナビゲーションを行うfluoroscopic navigationがある。

両者にはいまだ精度面で差があり，前者ではおよそ0.5mm以下，後者は0.8～1.2mmの精度である。したがって，高精度が要求される頚椎手術では術前CT像の取り込み，プランニングが必要となっている。

術前に1mmスライスで撮像したCTデータをワークステーション(Silicone graphics)に取り込み，三次元脊椎モデルをコンピュータ上に構築する。そこで，刺入を予定する椎弓根に太さ2.5mmのプランニング像を水平面，傍矢状断面，椎弓根断面を確認しながら作成する(**図2**)。スクリュー長は20～22mmで設定しておく。スクリュー刺入点は中下位頚椎では外側塊外縁やや頭側に陥凹があり，これがよいメルクマールとなる。外側縁外縁から内側約3～5mmで，刺入角度は内側向き30～35°程度が望ましいが，患者の椎弓根角には個人差がある。

CT像での解剖学的形状と患者の体格をみてプランニングするが，刺入角度を大きくとり

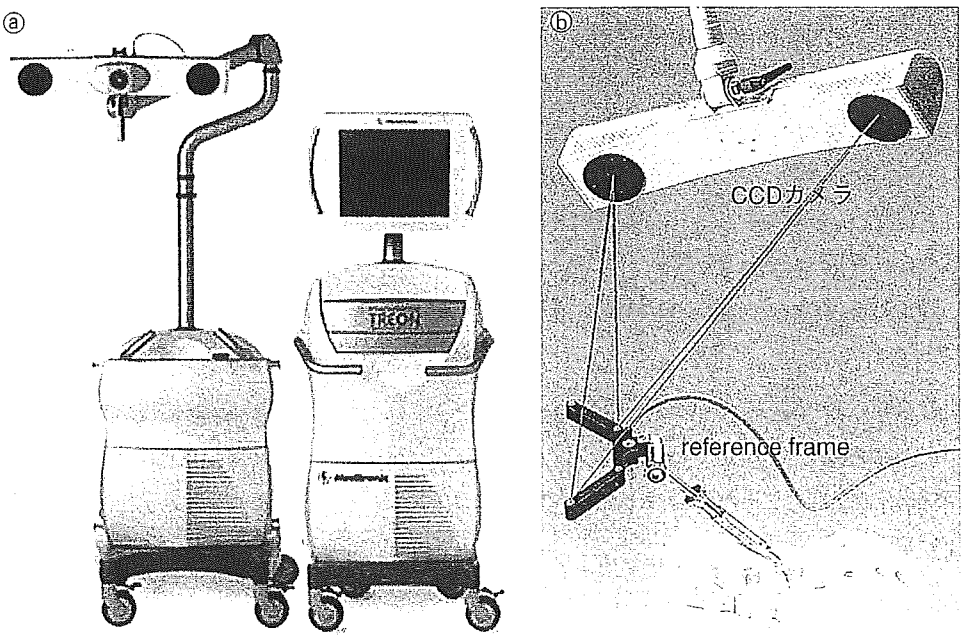


図1 代表的なサージカルナビゲーションシステムの概要
ⓐ：システムは術中情報を表示するワークステーションと赤外線信号を送受信する器具よりなる (Stealth Station Treon, Medtronic Sofamor Danek社製)。
ⓑ：棘突起に設置したreference frameからの光学信号をCCDカメラで捉え，サージカル空間の座標軸を構築する。

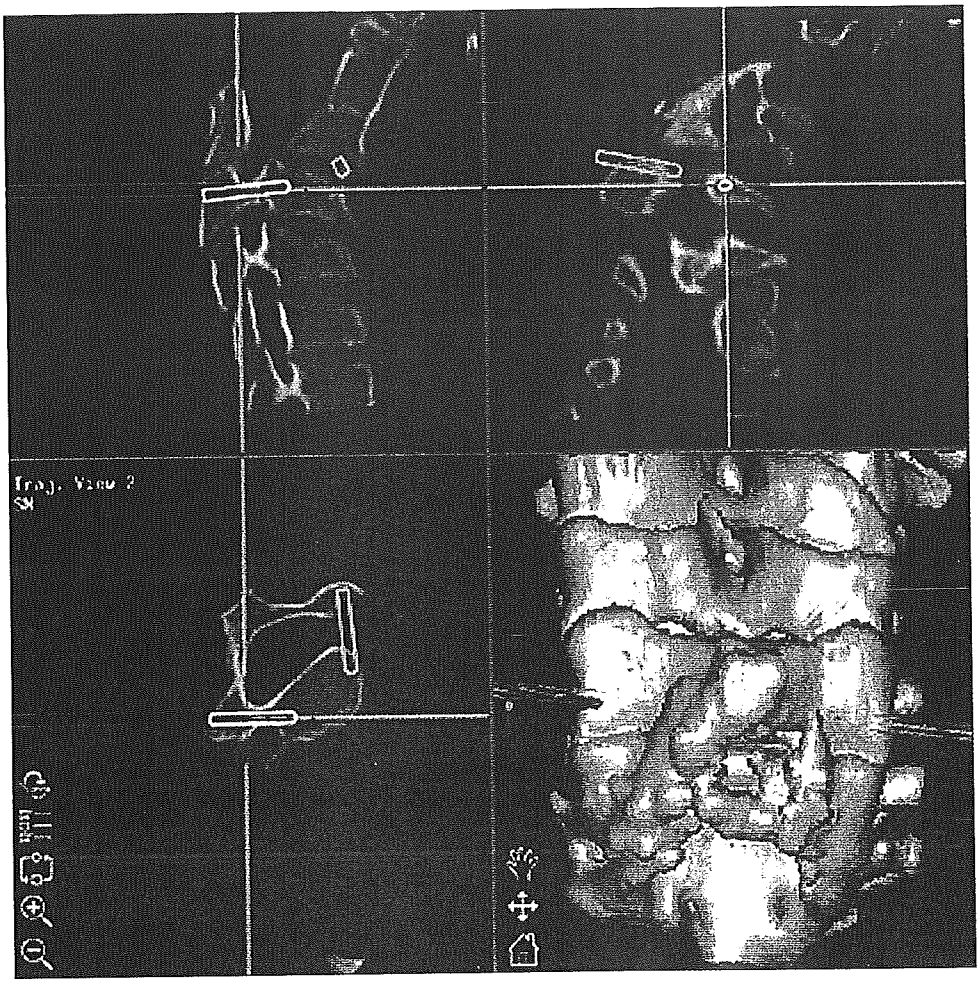


図2　術前プランニングと実際のナビゲーション画面
水平面(左下)，傍矢状面(左上)，椎弓根断面像(右上)において適切な位置の径2.5mmのプランニング像を作成する(黄色，緑色)。青色は術中のインストゥルメント先端の位置であり，椎弓根手前に位置している。

すぎると，頚部後方筋群と皮切の関係で，実際の刺入角度とかけ離れてしまう可能性があり注意を要する。また椎弓根径が三次元モデル上の計測で3mm以下の場合には，スクリュー刺入は避けたほうがよい。次にpoint registration用の照合点を5～6点設定しておく。精度が出やすく，再現性がよい点として，棘突起先端，スクリュー刺入点，左右の下関節突起尾側端を設定するとよい。

以上のプランニングには約20分を要する。また頚椎変形や奇形が存在する場合は，この三次元モデルをさまざまな方向から検討することで，術中の骨切除部位，固定アンカーの設定を含む詳細な術前計画が可能となり，きわめて有用である。

● 手術手技

▩ 器材の設置および準備

術者は患者の頭側に立ち，ナビゲーションモニターと，Cアームを患者の側方，赤外線感知装置を術野から尾側1.5～2mの場所におく。十分な展開ののち，ナビゲーションを行う椎の棘突起にreference frameを設置する。骨粗鬆症が強い症例や小児例では棘突起の骨強度が低いため，骨折しないよう注意する。

照合操作ではコンピューターを接続されたsharp probeを用いて，すでに設定してある照合点を画面上で確認しながら，患者の該当する解剖学的位置をプロットしていく(図3)。

point registrationで4mm以下の精度が確保されると，surface registrationに移行できる。residual errorが2mm以下でナビゲーション可能であるが，頚椎手術では0.3～0.5mmにコントロールされていることが望ましい。

▩ 椎弓根スクリューの刺入

われわれが独自に開発したimage guided

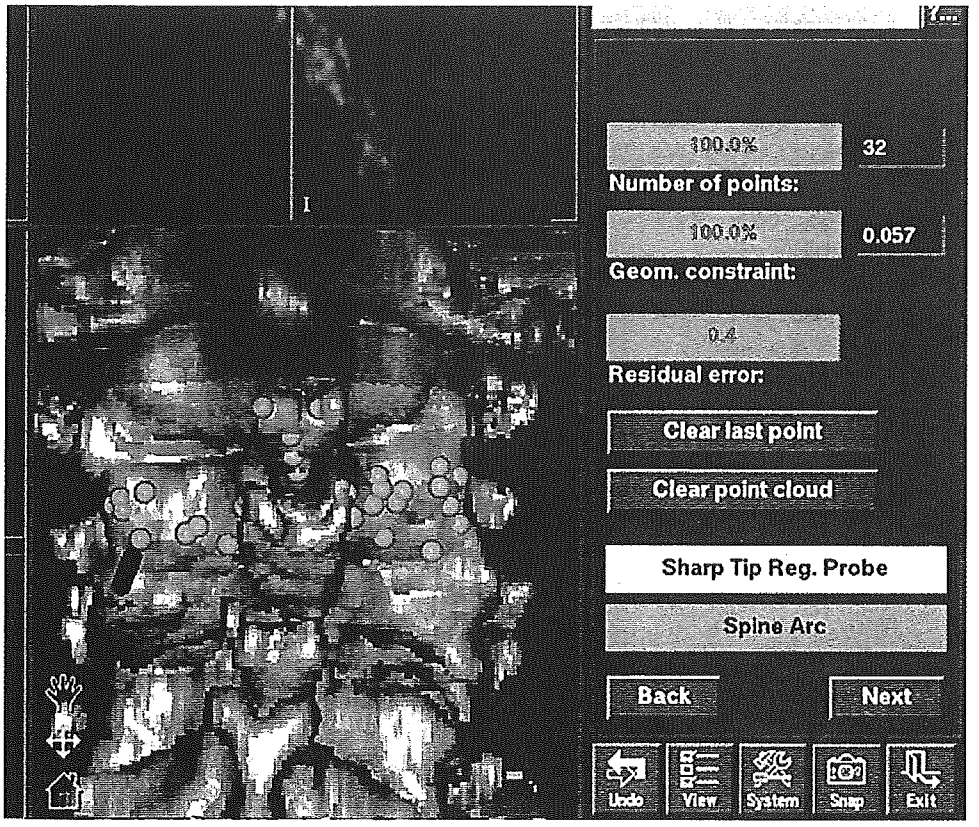


図3　照合画面
ナビゲーションする椎の後方要素をランダムにプロットし，surface registrationを終了している。residual errorは0.4mmと表示され，良好な精度が確保されている。

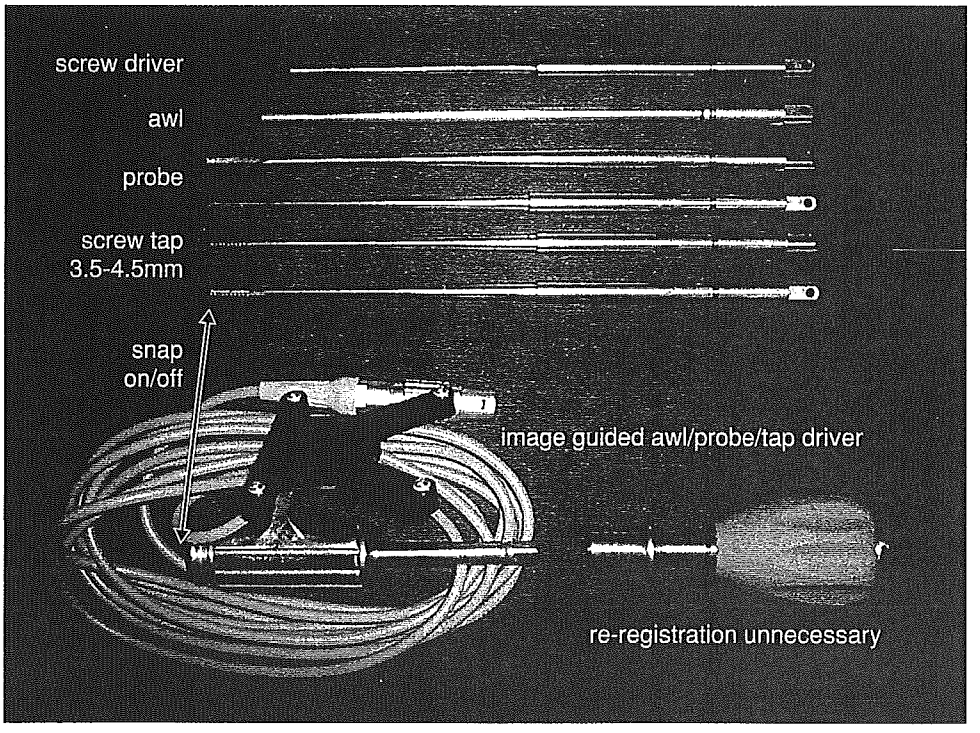
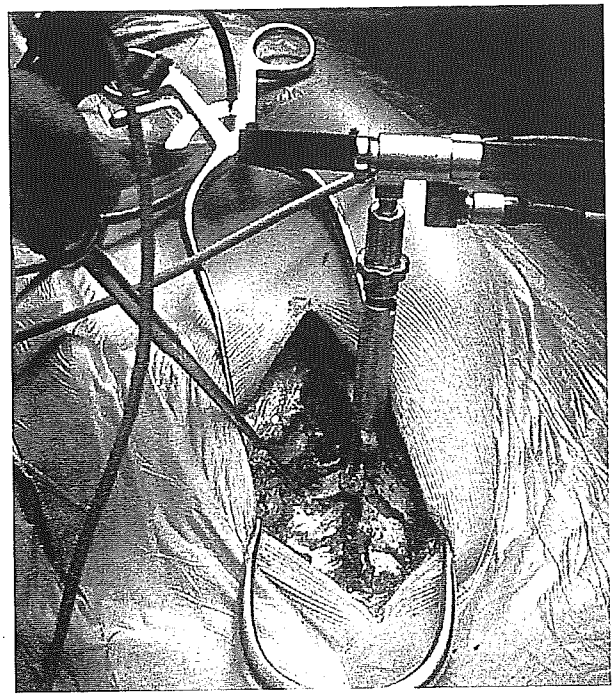


図4　頚椎用image guided instrument（実用新案3092558号）
頚椎椎弓根スクリュー用のインストゥルメントをナビゲーション用に改良し，既存のimage guided awl/probe/tap driverに簡便に接続できるようにした。一度の先端照合ですべてのインストゥルメントの先端位置をreal-timeにナビゲーションできる。

awl/probe/tap driver（Medtronic Sofamor Danek社製）は，実際の骨内に刺入するプローブ，タップ，スクリュー先端の三次元的位置を把握するために開発された（図4）[3]。

頚椎椎弓根スクリュー用のインストゥルメントをナビゲーション用に改良した特殊器具

図5　頚胸椎変形に対する椎弓根スクリュー刺入
ナビゲーションする椎の棘突起にreference frameを設置し，image guided instrumentを用いてスクリュー刺入を行う。図はimage guided tapを用いて，刺入孔を作製している。



を脱着することで，awl操作からスクリュー先端に到る一連の器具先端位置をreal-timeにかつ三次元的に把握できるようにしたものである(実用新案3092558号)。

まず刺入点を専用awlまたはエアトームで穿孔し，次に専用プローブ，タップ，スクリューの順に先端位置を確認しながら刺入する(図5)。高度の頚椎症や小児で椎弓根が硬化している場合，ナビゲーション用awlを用いて椎弓根内での先端位置を確認しながら椎体まで穿孔すると，比較的安全にルートを確保できる。また器具刺入中に起こるナビゲーション画面の乱れは，手元を1～2秒静止させることで解消できる。また安全のため，Cアームは併用するようにし，適宜側面像を確認している。

椎弓切除椎では上下椎と骨癒合している場合を除いて，現状ではナビゲーションは不可能だが，上下の椎に先にナビゲーションを用いて刺入を行えば，その刺入点や刺入角度が参考になり，穿破を減少できる。

図6　【症例1】頚椎椎弓切除後後弯
9歳，女子。
ⓐ：硬膜内髄外腫瘍摘出後に発生した47°の著明な後弯変形。
ⓑ，ⓒ：ナビゲーションシステムを併用した椎弓根スクリュー固定(C2—5)。術後1年で矯正損失なく，骨癒合が得られている。
ⓓ，ⓔ：術後CTではスクリューは適切に刺入されている。