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ORIGINAL PAPER

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New method of evaluating the surgical margin and safety margin for musculoskeletal sarcoma, analysed on the basis of 457 surgical cases

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Abstract The evaluation of surgical margin is useful in determining the curative success of surgical treatment of musculoskeletal sarcoma and the degree to which later surgery will be reduced by the preoperative therapy. However, until recently no reliable evaluation method has been developed for these purposes. In this paper we propose a new method for evaluating the surgical margin as drafted in 1989 by the Bone and Soft Tissue Tumour Committee of the Japanese Orthopaedic Association (JOA). In this method, surgical margin was classified into four types based on the distance between the surgical margin and the reactive zone of the tumour. These classifications of surgical margin (in order of surgical extent) are curative wide margin (curative margin), wide margin, marginal margin, and intralesional margin. The surgical margin is said to be curative if the margin is more than 5 cm outside the reactive zone. It is referred to as wide if the margin is less than 5 cm. Similarly, a margin that is in the reactive zone is considered as marginal, and a margin passing through a tumour as intralesional. Moreover, wide margin is classified as adequate (at least 2 cm outside the reactive zone) or inadequate (1 cm). In our evaluation, a "thin" barrier is considered to be a 2-cm thickness of normal tissue, a "thick" barrier as a 3-cm thickness, and joint cartilage is said to be equivalent to a 5-cm thickness. In addition, a surgical margin that is outside a barrier, with normal tissue between the barrier and the reactive zone of the tumour, is considered to be curative. This method was applied in 457 cases (involving 499 surgeries) at the Cancer Institute Hospital to determine clinical significance in the treatment of musculoskeletal sarcoma (1979–1994). From the results of this study we were able to conclude that this evaluation method can be highly useful in clinical practice for establishing optimum surgery. Moreover, we found that the safety margin for high-grade musculoskeletal sarcoma is a curative margin providing an adequate wide margin of 3 cm or more when preoperative therapy is not performed or is not effective, while the safety margin for high-grade sarcoma that responds to preoperative chemo- or radiotherapy seems to be an adequate wide margin of 2 cm. Here, radiotherapy is more effective compared to chemotherapy for reducing surgical margin. An inadequate wide margin, however, combined with radiotherapy, is not enough to ensure local curative success following surgery for musculoskeletal sarcoma. Therefore, we have determined that these procedures should be used only when establishing a safety margin is difficult, even if ablasion or various reconstructive modalities are applied. On the other hand, for low-grade sarcoma, an inadequate wide margin can be considered as safe.

Key words Surgical margin · Safety margin · Musculoskeletal sarcoma · Surgical treatment

Introduction

At present, a range of limb salvage procedures is the most widely accepted treatment for musculoskeletal sarcoma and, in the surgical planning for almost all lesions, these procedures should be considered first. However, procedures used to salvage limbs vary considerably among cancer specialists. This difference is caused by individual attitudes of physicians that stem from their personal experience rather than being based on theoretical or clinical studies. The best means for developing clinical evidence is through analysing surgical margins of operative procedures, then following up the results to draw conclusions. Unfortunately, despite a pressing need to determine which oncological surgical procedure works best according to theoretical

Work dedicated to Dr. Haruo Sugano on the occasion of his 70th birthday. The material of this paper was essentially presented at the 60th Anniversary Symposium of the Cancer Institute and the Cancer Institute Hospital, Tokyo, held in September 1994

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results, there has been no accumulation of reliable data. This is because almost all descriptions of surgical margin in clinical records have been uncertain and ambiguous. Part of the reason for this ambiguity comes from a lack of well-documented criteria that can be used to evaluate the effectiveness of surgical margins.

Dr. W. F. Enneking was the first to address this concern, and eventually introduced the concept of surgical margin evaluation (Enneking et al. 1980). This evaluation system has since become widely used throughout the world and, in fact, is occasionally referred to in the medical literature. However, for the most part these surgical margins seem to be evaluated or dealt with on an informal basis, depending mainly on the largely subjective impressions of surgeons whose examples are the already-known results from previous cases. Since the records of such cases are probably too ambiguous to permit a study of surgical margin, there has been a need for reliable, statistically valid data.

With this intent, we began in 1979 to evaluate all fresh surgical specimens and precisely record the surgical margins, as described later. Moreover, in 1980 we began using the criteria developed by Enneking et al. (1980) for evaluating surgical margin. As our study proceeded, we grew increasingly convinced that the Enneking evaluation system was not always wholly satisfactory from a practical standpoint.

Our intentions in adopting a comprehensive evaluation system for the surgical margin used for musculoskeletal sarcoma were as follows:

1. We wanted to determine the least surgical margin necessary to ensure local cure by surgery alone.
2. We wanted to determine the reduced "safety margin" after preoperative adjunctive therapy.
3. On the basis of those results, we wanted to know the extent of the reducible surgical margin, which seems to be influenced by the effectiveness of preoperative adjunctive therapy and the aggressiveness of the tumour.
4. We also wanted to be able to establish optimum surgical planning through the application of multidisciplinary treatment.
5. Finally, having provided a reliable prognosis for local recurrence, we wanted to ensure that preventive treatment could be carried out postoperatively as soon as possible, so as to achieve local cure consistently.

To achieve these purposes, meticulous modification and correction of the basic criteria were attempted beginning in 1980 at the Cancer Institute Hospital. By 1989, a reliable, statistically valid evaluation method for surgical margin had been largely completed. Soon after it was finally established through discussions by a small group of specialists designated by the Japan Orthopaedic Association Musculoskeletal Tumour Committee (chaired by A. Tateishi), and accepted by the JOA (chaired by N. Toriyama) under the title *An evaluation method of surgical margin for musculoskeletal sarcoma (1st Preliminary Criteria) (1989).*

The following explains this newly established method for precisely evaluating surgical margins and the results of studies on patients that have helped to refine and support the theoretical assumptions.

Procedure for evaluating surgical margins

Pre-evaluation manipulation of surgical specimens

Typically, various distortions are observable in surgical specimens, which must be taken into consideration so that they do not interfere with the evaluation of results. The evaluation can be conducted with either fresh surgical or formalin-fixed specimens. However, in the former case, protrusions occur on the sectioned surface, which make the photographic recording of results more difficult, so that later review and analysis of surgical specifications become somewhat problematic. On the other hand, with formalin-fixed specimens, tissue shrinkage can also interfere with the evaluation; nevertheless, this type of specimen leads to better photographic preservation of objective evidence. Consequently, for almost all cases in this study, formalin-fixed specimens were prepared and photographs were taken of sectioned surfaces at the very least in transverse and longitudinal planes, and diagrams were carefully sketched.

To reduce the effects of distortions caused by formalin fixation, several techniques have been used.

1. If it is relatively small, during formalin fixation the operative specimen is fixed as a preliminary measure under normal tension on the fixing plate.
2. For a larger specimen, before it is separated from the original site, two points on the muscle are marked with threads at an interval of 5 cm to determine the contraction rate compared to the distance between the threads after formalin fixation. Correction can then be made to the distance between the tumour and the surgical margin.

Manipulation immediately after operation

If the surgical margin is suspected to be less than intended, an excision is taken from the suspicious region for tentative evaluation of the surgical margin. If an inadequate surgical margin is observed at that time, adjoining residual tissue is additionally removed. Moreover, material for proper diagnosis, electron microscopic investigation etc. is collected from another site where the surgical margin is considered to be completely adequate.

Manipulation on the first day

After formalin fixation for 1 day, excision is done on the surgical specimen transversely or longitudinally (the direction is decided according to the surgeon's requirements). The divided surgical materials are soaked in formalin overnight.

Manipulation on the second day

A new excision is conducted on the surgical specimen in the opposite direction from the first day's sectional plane

and the surgical margin is evaluated on the entire circumference, putting together the transverse and longitudinal sectional planes. If an inadequate margin is suspected at another site, another excision is carried out as appropriate to determine whether the suspicion is correct. Moreover, the findings from the excisions must be sketched precisely, and photographs of the same cut surface must be taken to record the evaluation and for future study (Fig. 1).

Criteria for evaluating the surgical margin

Classification and definition of surgical margin

For this evaluation method, surgical margins are divided into four categories: curative (wide) margin, wide margin, marginal margin, and intralesional margin.

Curative wide margin (curative margin)

This is a surgical margin that passes through the region outside the reactive zone at a distance of more than 5 cm from the tumour-reactive zone (the value found after correction for contraction due to formalin fixation), or the equivalent thickness as explained below.

Wide margin

This is a surgical margin that is not enough to be curative but is still outside the reactive zone. Moreover, wide margin is further classified into two types: adequate and inadequate wide. An adequate wide margin is a margin that is 2 cm or more from the reactive zone and an inadequate wide margin is a margin that is 1 cm outside the reactive zone.

Marginal margin

This is a surgical margin that passes through the reactive zone. When a sarcoma with strong capsular formation is exfoliated and enucleated easily from the capsule-like tissue, the surgical margin for this procedure is estimated to be marginal. However, the surgical margin of an excision that is performed inside the capsule-like tissue, which adheres tightly to the tumour, is defined as an intralesional margin, as described below.

Intralesional margin

This is a surgical margin that passes inside the tumorous parenchyma.

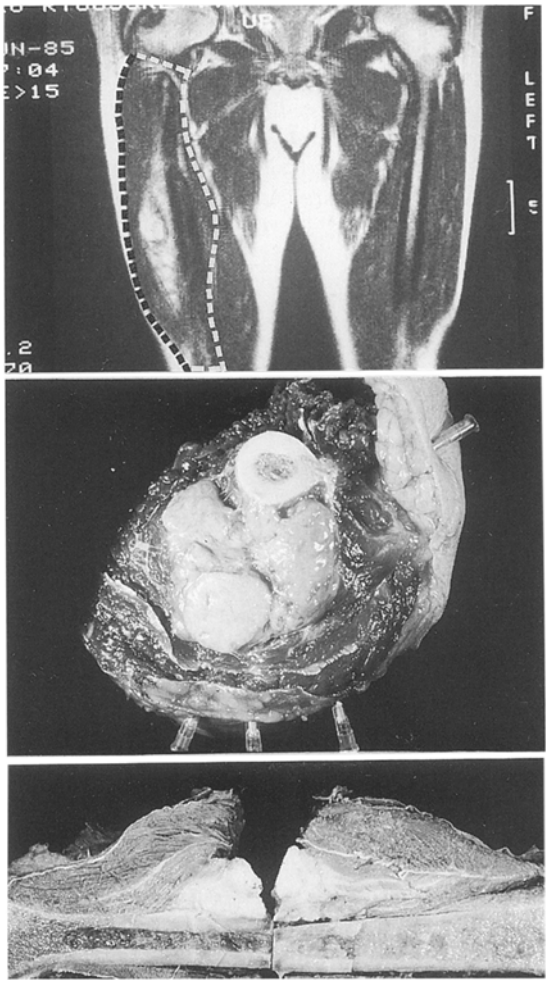

Fig. 1 Malignant fibrous histiosarcoma of the thigh involving the femur (*upper*; MRI). *Dotted line* surgical line by curative margin. Surgical specimen prepared for evaluating surgical margin (*middle:* axial section). (*lower:* coronal section)

Principles for evaluating surgical margin

1. For evaluating surgical margin on the transverse plane (that is, when a barrier exists between the surgical margin and the tumour), the barrier is converted into tissue equivalence with a definite thickness to establish a specifiable "distance" between the tumour and the surgical margin. However, when the barrier adheres to the tumour (that is, when there is no mobility between the tumour and the barrier), this conversion does not apply. (Note: there are exceptions for thick barriers as described later.)

2. In this calculation, thin fascia is considerd to be the equivalent of 2 cm normal tissue, thick fascia as 3 cm, and joint cartilage as 5 cm. Moreover, a surgical margin passing just outside of fascia which is separated by normal tissue from the tumour is also calculated to be 5 cm regardless of the barrier's actual thickness.

3. For evaluation of the thickness of the tissue from the reactive zone, it is permissible to assess several millimetres to 1 cm as 1 cm, 1 cm to 2 cm as 2 cm, and so on.

4. For the curability of the surgical procedure, the level actually achieved is expressed by the lowest of all the margins, because it is mainly the lowest margin that influences the potential for local cure of the entire surgical procedure. These procedures are referred to as curative, wide, marginal, and intralesional irrespective of any limb salvage and ablative surgical steps that are subsequently taken.

5. In this evaluation of surgical margin, the relevant terms are defined as follows.

Barrier

Barrier refers to tissue that has any resistance against tumour invasion and includes fascia, joint capsule, tendon, tendon sheath, periosteum, vascular sheath, cartilage, pleura, peritoneum, and epineurium (however, the cruciate ligaments of the knee joint and the ligamentum tere of the hip joint are excluded in a longitudinal evaluation). All barriers except for joint cartilage (which is exceptionally strong and is therefore evaluated separately, as mentioned above) are divided into thick and thin types. A thick barrier means physically strong membranous tissues of various thicknesses with a white lustre through which underlying tissue cannot be seen. For instance, the iliotibial band, joint capsule, and peritoneum of an infant or young child fall into the thick-barrier group. On the other hand, a thin barrier means weaker membranous tissue through which the underlying tissue can be seen yet which contains healthy fascia of individual muscle, the peritoneum in adults, vascular sheath and epineurium.

Reactive zone

This is the discoloured zone around a tumour, observable by inspection, which is composed of haemorrhagic tissue, degenerative muscle, or oedematous and cicatrical tissue. The reactive osteosclerotic area observed at the periphery of a slowly growing bone lesion is also regarded as the reactive zone. Secondary haemorrhages, such as those caused by biopsy or pathological fracture, are treated somewhat differently. For instance, when the surgical margin passes through a fresh haemorrhagic area, the latter is considered to be reactive zone. But when the surgical margin exists outside the haemorrhagic area, the evaluation of surgical margin is made from the site of the original reactive zone and the haemorrhagic area itself is ignored (cf. the evaluation of the surgical margin in a tumour associated with secondary haemorrhage.)

Evaluative treatment of cicatrical tissue differs according to whether preoperative adjunctive therapy (chemotherapy and/or radiotherapy) has been carried out. That is, when preoperative therapy is in concurrent use, any peritumourous cicatrical tissue that adheres firmly to the tumour is regarded as being part of the tumour regardless of whether tumour cells are actually present, because the cicatrical tissue may have been caused by necrotizing of tumour

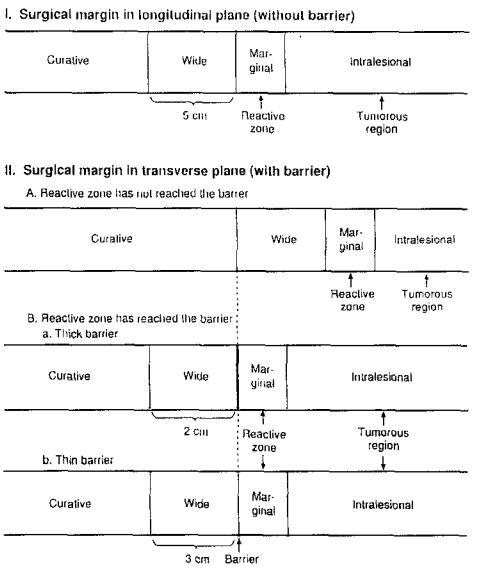

Fig. 2 Diagram for evaluation of surgical margin

tissue. On the other hand, in those cases with no preoperative therapy, any scar-like tissue is considered to be part of the ordinary reactive zone. Moreover, when the surgical margin of cases untreated preoperatively passes through the scar-like tissue, either an intralesional margin or marginal margin is assumed depending on the histological finding of whether or not tumour cells are present. Usually the term pseudocapsule is ambiguously used; however, for this evaluation method, a pseudocapsule is divided into two categories. The first comprises membranous tissue that is firmly connected to the tumour and the second membranous tissue that is loosely connected to the tumour. The former is considered to be the zona compressio of tumour parenchyma.

Evaluation of surgical margin in practice

During the evaluation of surgical margin, we observed that local conditions can sometimes influence the results. Consequently special criteria were devised to exclude these influences. However, this requires ongoing individual assessment of the reliability of the criteria under each type of local condition. This makes it necessary for the evaluation results of surgical margins to be adjusted and recorded separately for every definable condition. Over time it should be possible to apply the adjusted individualized criteria to simplify handling of this evaluation method by making it possible to ignore the local conditions.

Evaluation of initial operative specimens

Evaluations for initially operated cases are indicated in Fig. 2. In this group of cases, curative margin with no barrier (in the longitudinal plane) is determined to be a surgical margin more than 5 cm outside the reactive zone

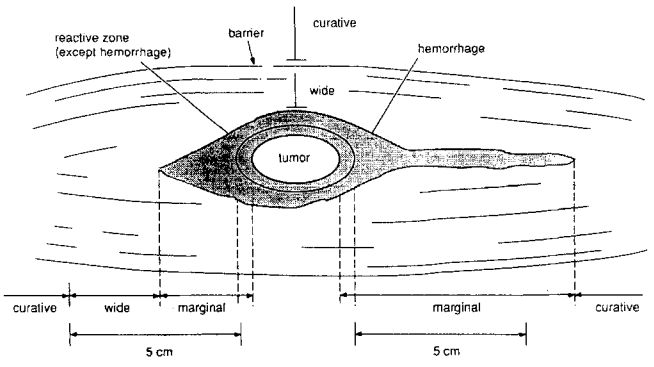

Fig. 3 Evaluation of tumour associated with secondary haemorrhage and additionally operated specimen. No tumour is observed upon further operation. The operative scar is regarded as part of the reactive zone

(Fig. 2 I). Curative margin with a barrier (in the transverse plane) differs according to the thickness of the barrier and its relationship to the reactive zone. When the barrier is separate from the reactive zone, the surgical margin outside the barrier is defined as being curative regardless of the thickness of the barrier and the distance of normal tissue from the barrier to the reactive zone (Fig. 2 II A). When the barrier is adjacent to the reactive zone and remains removability along with the tumour, the evaluation of surgical margin is calculated by converting the barrier into 3 cm or 2 cm depending on whether the barrier is thick or thin (cf. reactive zone). Therefore, a surgical margin more than 2 cm distant from a thick barrier and a surgical margin more than 3 cm distant from a thin barrier are evaluated as curative (Fig. 2 II Ba, b). When the barrier adheres to the tumour, the barrier's site is evaluated as being the tumour boundary itself in principle and the barrier is judged to have lost its function. However, when the barrier is thick, its exterior tissue can be exfoliated easily. When the barrier surface is inspected, moreover, if it is found to be normal and without discoloration, the margin is evaluated by deducting 1 cm from the original value of the barrier (3 cm). This is because the barrier function, in this instance, would be regarded as being partially residual (Fig. 2 II Bb).

Evaluation of additional operative specimens and evaluation of the surgical margin of tumours associated with secondary haemorrhage

Figure 3 shows how these two categories are evaluated. Since no tumour exists at the time of the additional operation, evaluation is performed by regarding as the reactive zone the operative cicatrix in the region where the tumour is considered to have been present. When there is a widespread area of haemorrhage, the surgical margin is evaluated as being marginal, while the surgical margin outside the haemorrhagic area is defined as being the same as if no haemorrhage had occurred. Such haemorrhages are observed in cases after biopsy or are associated with pathological fracture.

Evaluation of operative specimens of recurrent tumours, of specimens associated with skip metastasis or lymphatic metastasis, and of specimens with venous thrombosis

For operative specimens of recurrent tumours, it a curative margin is defined when (a) the tumour can be removed from outside a barrier not only together with the recurrent tumour but also with tissue that has lost its natural structure, including the operative scar of the skin, or (b) the tumour can be removed so that it is covered with a layer of normal tissue 5 cm or greater in thickness without disturbance of the structure. By comparison, a surgical margin is defined as marginal when it passes through the cicatrix in the periphery of the recurrent tumour, and is defined as wide when it passes through tissue that appears to be normal by inspection but is not to the extent required for curative margin. A curative margin in which multiple recurrent tumours are observed is the same, and the margin is presumed to have been excised at a site 5 cm outside the domain including all of the recurring lesion and all tissue that has lost its normal structure at the periphery (Fig. 4). Similarly, when skip metastasis, lymph node metastasis, or venous thrombosis is observed, a surgical margin at a distance of 5 cm not only from the main lesion but also from a lesion caused by the skip metastasis, lymph node metastases, or venous tumour thrombus is defined as a curative margin. At that time, however, the fatty tissue in which a lymph node metastasis or tumour thrombus is observed must be removed extra-fascially with the main tumour in the same longitudinal range as the curative margin of the main tumour and the secondary lesions (Fig. 5).

Evaluation of surgical margin when the surgical line accidentally cuts into the tumour edge

In the event that the surgical line accidentally cuts into the tumour edge but does not reach the tumour parenchyma, or when the tumour cells have not escaped even if the excision does reach into the tumour, the evaluation of the final margin excised is determined largely by the closure of the region of the route taken. The evaluation is made similarly

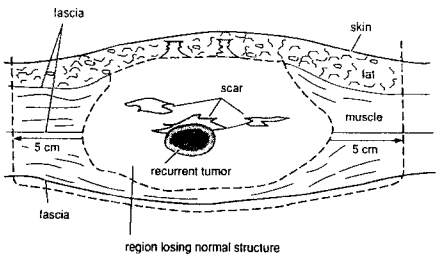

Fig. 4 Evaluation of surgical margin in recurrent tumour. Curative margin: a margin (*dotted line*) at 5 cm outside the domain including all the recurrent lesion, scar tissue and region losing normal structure. Wide margin: a margin that is less than the curative margin and passing outside the reactive zone or operative scar tissue

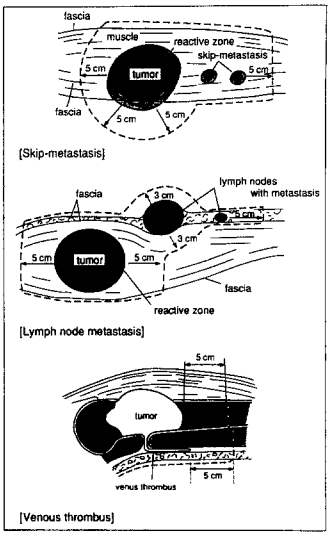

Fig. 5 Evaluation of tumour associated with skip metastasis, lymph node metastasis or venous thrombus. Curative margin: a surgical margin (*dotted line*) at 5 cm not only from the main tumour but also from the associated lesions. Wide margin: A surgical margin less than the curative margin and oustide the reactive zone of all lesions

when the intermuscular aerolar space is opened during surgery.

Evaluation of a surgical margin that passes through a joint cavity

When the surgical margin passes through the joint, the evaluation is not made in this region but in an adjoining region if no discoloration is present on the surface of the articular synovial membrane. In this case, the evaluation is marginal margin if discoloration of the synovial membrane is present and intralesional margin if the tumour is exposed. The same applies to the evaluation of intermuscular aerolar tissue. That is, in practice, if the margin at the intermuscular aerolar tissue region is wide, the evaluation of surgical margin may be made in another adjoining region instead of this region. On the other hand, if fatty tissue exists between the muscular bundles, this surgical margin is not considered curative unless it is separate from the reactive zone by more than 5 cm.

Assessment of local curability by surgical margin

Evaluation of surgical margin was conducted in 457 cases (499 surgeries, 80% involving limb salvage) of musculoskeletal sarcoma at the Cancer Institute Hospital (1979–1994) to assess local curability (Table 1). The cases included 191 cases of bone sarcoma and 266 cases of soft-tissue sarcoma.

In each case, the tumour was removed according to the principles of curative wide resection (Kawaguchi et al. 1987). That is, in this surgery, fascial tissues that exist between individual muscles, cartilage, and the joint capsule

Table 1 Summary of sarcoma cases and surgery 1979–1994. *MFH* malignant fibrous histiosarcoma, *ASPS* alveolar soft-part sarcoma

Type of sarcoma	Cases	Surgeries
Bone		
High grade	140	147
Osteosarcoma	104	108
Ewing's sarcoma	16	16
MFH	12	15
Other	8	8
Low grade	51	55
Chondrosarcoma	31	33
Chordoma	10	10
Parosteal osteosarcoma	4	4
Other	6	8
Soft tissue		
High grade	191	213
MFH	75	85
Synovial sarcoma	29	30
Liposarcoma	19	19
Rhabdomyosarcoma	12	13
Epithelioid sarcoma	7	10
Ewing's sarcoma	6	6
Other	43	50
Low grade	75	84
Liposarcoma	33	35
MFH	11	12
ASPS	10	13
Other	21	24

are considered to serve as a barrier against tumour invasion and the tumour removal is conducted as if the lesion were wrapped by these barrier tissues. When no suitable barrier exists, the tumour is removed with as much surrounding tissue as possible. For the analysis of cases, the sarcomas were classified into two groups of high-grade and low-grade sarcoma. Figure 6 shows the cumulative survival rates of the two groups for bone and soft-tissue sarcoma. The local curability of the two groups for each surgical procedure is shown in Figs. 7 and 8. An analysis of high-grade sarcomas found that the cumulative local curative success by curative procedures was 86% (local recurrence rate 14%; all occurring from skip metastasis or lymph node metastasis), by adequate wide procedure 86% (recurrence 14%), by inadequate wide procedue 66% (recurrence 34%),

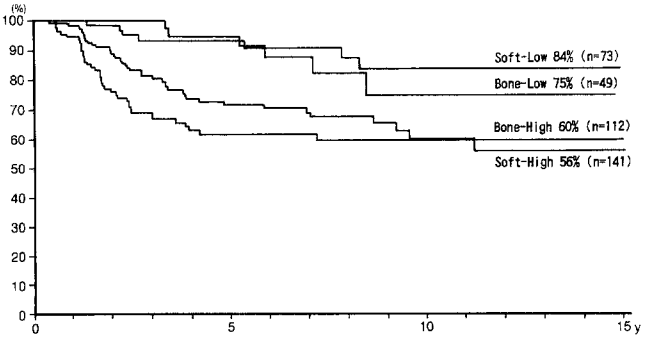

Fig. 6 Cumulative survival rate of patients with musculoskeletal sarcomas (375 cases: M1 eliminated). Analysed by the Kaplan-Meier method

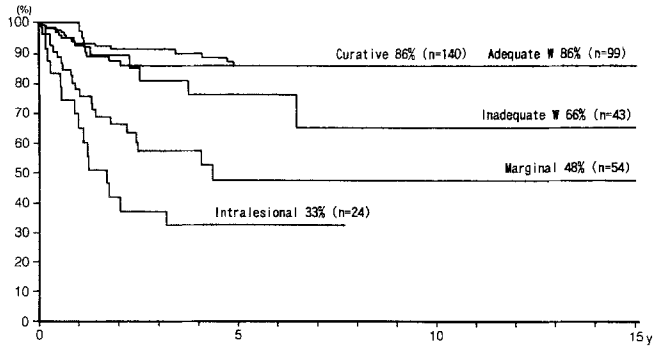

Fig. 7 High-grade sarcomas (360 surgeries): surgical procedures and local curative success. Analysed by the Kaplan-Meier method

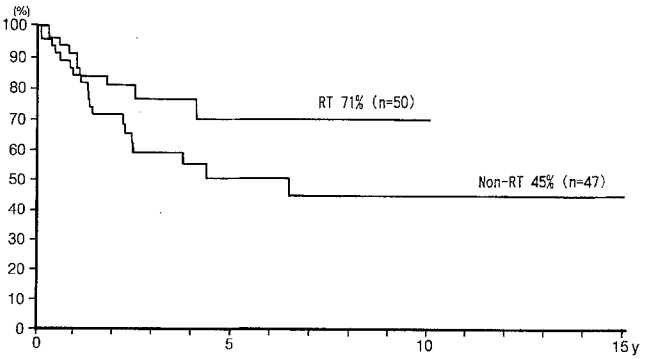

Fig. 9 Inadequate and marginal procedures: radiotherapy and local curative success. Analysed by the Kaplan-Meier method

by marginal procedure 48% (recurrence 52%), and by intralesional procedure 33% (recurrence 67%). Here, local recurrence is defined as a return of the same lesion as primarily occurred not only at the site around the operation wound but also at the whole site of the affected limb apart from the wound. On the other hand, the local curability of low-grade sarcomas was 82% (recurrence 18%) by curative procedure, 84% (recurrence 16%) by wide procedure, 88% (recurrence 12%) by marginal procedure and 0% (recurrence 100%) by intralesional procedure. In curative and adequate wide procedures for high-grade sarcoma, moreover, there was seen to be no significant statistical difference in local curability between good responders to preoperative therapy and poor responders. However, most poor responders were treated by procedures involving 3 cm or more extensive margin, while nearly all cases in which 2-cm-wide margins were used were good responders.

These results mean that almost all cases of high-grade musculoskeletal sarcomas could be controlled by curative procedures without the aid of chemo- or radiotherapy. Moreover, statistically local recurrence of high-grade bone sarcoma could be controlled by adequate wide procedures as well as by curative procedures. However, these results can be ensured only when more extensive wide procedures are chosen for poor responders to preoperative chemo- or radiotherapy and less-extensive adequate wide procedures are chosen for good responders. This suggests that effective preoperative chemo- or radiotherapy might be useful for reduction of the surgical margin on condition that an adequate wide procedure is always established.

On the other hand, local curability by inadequate wide or marginal procedures is 66% (recurrence 34%) and 48% (recurrence 52%) respectively. These results are obviously poorer than those achieved by an adequate wide procedure. Figure 9 shows the relationship between local curability and radiotherapy with these procedures.

This suggests that local curability by inadequate wide and marginal procedures is also improved by radiotherapy. However, there was no obvious improvement of local curability in the cases where these procedures were used, when only preoperative chemotherapy was performed. These results suggest that preoperative radiotherapy should be used when less than adequate wide procedures are predicted. In low-grade sarcoma, the local effectiveness of curative to marginal procedures is statistically similar and the local recurrence rate is about 10%. From these results, we determined that local recurrence following curative procedures is caused by skip metastasis, while recurrence following wide and marginal procedures is caused by residual lesions around the surgical site.

The surgical procedure for cases with venous thrombus was mainly evaluated as intralesional.

Cases of intralesional procedures showed high recurrence regardless of grades. However, the local curability of

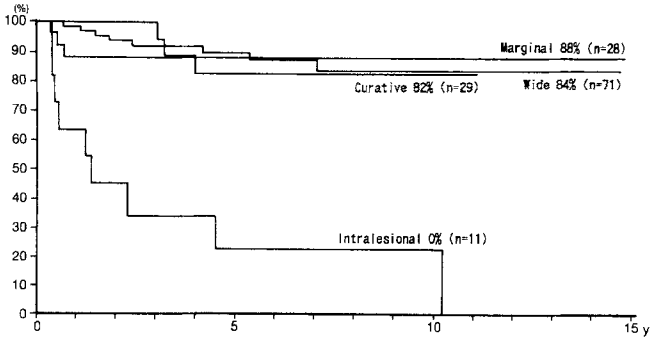

Fig. 8 Low-grade sarcomas (139 surgeries): surgical procedures and local curative success. Analysed by the Kaplan-Meier method

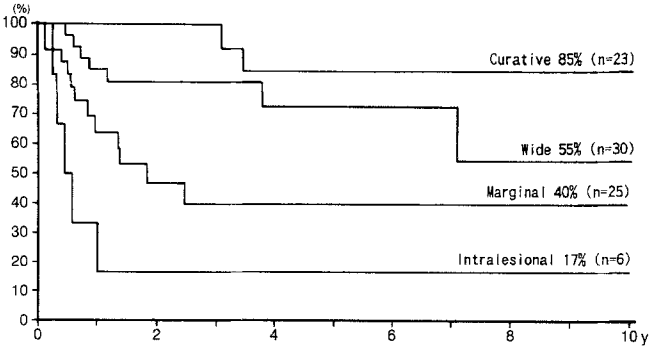

Fig. 10 Recurrent tumours (84 surgeries): surgical procedurs and local curative success. Analysed by the Kaplan-Meier method

high-grade sarcoma was better than that of low-grade. These results seem to suggest that low-grade sarcoma is radioresistant. That is, adjunctive radiotherapy for low-grade sarcoma is less useful in making an insufficient surgical margin safer.

These results were recognized without inconsistency for both singly and additionally operated cases. However, the results from recurrent cases are somewhat different (Fig. 10). That is, favourable local curability is achieved only by curative procedures, regardless of histological grade. This suggests that the local curability of recurrent cases is mainly influenced by tumour dissemination during previous surgery rather than by the invasive characters of the tumour. We therefore could conclude that the safety margin of musculoskeletal sarcoma is as follows.

1. For high-grade sarcomas treated by surgery alone or for non-responders to preoperative therapy, adequate wide margins of 3 cm or wider could be considered safe.
2. For high-grade sarcomas that have responded to preoperative chemo- or radiotherapy, an adequate wide margin of 2 cm is the safety margin.
3. For low-grade sarcomas, an inadequate wide or wider margin could be considered as the safety margin.

Statistically, marginal procedures also showed similar results to the more extensive procedures. However, if a marginal margin is attemped it results in an intralesional procedure that shows inevitable local recurrence. Therefore, inadequate wide or greater margins should be considered for safety in the surgical planning for low-grade sarcoma.

Generally, according to these considerations, limb salvage surgery can be carried out safely. However, as mentioned, it is necessary to pay close attention to the causes of recurrence following curative and more extensive adequate wide procedures. These are skip metastasis and lymph node metastasis, a third of which can be detected by medical imaging if meticulous attention is paid preoperatively. These harmful conditions also tend to occur in particular lesions such as epithelioid sarcoma, cutaneous angiosarcoma, rhabdomyosarcoma, and synovial sarcoma which occur in soft tissues, and in lesions such as Ewing's sarcoma on the bone. Therefore, the utmost effort is required to determine these conditions when definitive surgery is performed for these lesions. Especially in instances of epthelioid sarcoma and cutaneous angiosarcoma, it is better to achieve curative ablasion even if these conditions cannot be detected preoperatively. Moreover, venous invasion is a serious condition leading to inadequate surgery and this condition seems to be recognized in hugely expanded sarcoma.

Discussion

Although the concepts for evaluating surgical margin were initially proposed by Enneking, it eventually became clear that there were three main practical problems concerning his criteria (Enneking 1988; Enneking et al. 1980).

Size of the wide margin

The wide margin used by Enneking is too wide to indicate a certain cure. That is, it shows various degrees of curative success from radical margin to marginal margins. In Japan, moreover, surgery to obtain radical margins is not typically performed.

Ambiguities

Aspects of the evaluation criteria are unclear, causing different evaluators to reach different conclusions when given identical or similar data. For instance, when a tumour is proximal to a compartmental barrier, so long as it does not penetrate the barrier, even if it adheres to it, the Enneking criteria are unclear on whether the surgical margin outside the barrier should be evaluated as intracompartmental radical. Moreover, the reactive zone is not defined clearly when pre-operative treatment is administered.

Inconsistency due to the compartment concept

The evaluation develops inconsistencies at times because of classifications based on compartmentalization. For instance, in surgery the fascia of individual muscles works as a resistant membrane against tumour invasion, but in the Enneking-based evaluation system it is not regarded as a barrier; only tissues that separate each compartment are considered to be compartmental barriers.

According to the Enneking system, the radical margin for skin or subcutaneous lesions is defined as a margin greater than 5 cm from the reactive zone. Moreover, in the evaluation of extracompartmental lesions, a longitudinal surgical margin is evaluated as radical when it is at the same level as the origin or insertion of adjacent muscles. However, according to this concept the radical margin of a tumour that exists unevenly near the origin or insertion point of muscle can never be radical even if that area is removed. The same ambiguity is noted in intermuscular intracompartmental lesions; that is, when a lesion that exists in the space between the rectus femoris muscle and vastus intermedius muscle is located at the proximal site. Of course, even though this lesion is intracompartmental, a compartmental section never ensures a radical margin because this space is open at the proximal end.

Therefore, to resolve these ambiguities, our new evaluation method abandons the concept of compartment, and evaluation of the surgical margins instead depends on the distance of the surgical margin from the reactive zone.

With our evaluation system, to resolve the problem of margin width the category of wide margin is further divided into curative wide margin and wide margin, based on our experiences with curative wide resection. The former is a margin that seems to ensure cure, as does the radical margin of Enneking's system, while the latter is a margin that does not ensure it. Careful assessment shows that the effective-

ness of a curative margin is almost the same as that of a radical margin and this classification favours the study of the probability of reducing the surgical margin by preoperative treatment. Moreover, with the new classification system, it is possible to separate a wide margin into four 1-cm intervals and to evaluate the extent of reducing the surgical margin more precisely for each interval. To resolve the ambiguity problem, at the time of preoperative treatment the relationship between the barrier and the tumour and the extent of the reactive zone are defined more precisely. Finally, to resolve the problems of compartmentalization, the compartment concept is abandoned, and curative margin is defined as a surgical margin, or is equivalent that is, to more than 5 cm outside the reactive zone. This new approach to margin evaluation has proved that useful information can be generated to establish the optimum multidisciplinary treatment. Assessment, moreover, showed that, in cases of high-grade sarcoma that are treated by surgery alone, 3 cm seems to be adequate as the least safety margin, and in cases that receive effective preoperative chemo- or radiotherapy, the least safety margin seems to be an adequate wide margin of 2 cm. Moreover, for recurrent cases, only a curative margin is safe. In contrast, even though inadequate wide or marginal procedures carried out after radiotherapy showed local curability of a relatively high 70%, this result does not define the safety margin. Therefore, when predicting less than the safety margin, the procedure should be followed by reconstruction or ablasion, and only when other modalities would be expected to cause more difficulties (for instance, because of the tumour location or the patient's general condition), is an inadequate wide procedure combined with radiotherapy justified. On the other hand, the safety margin for low-grade sarcoma that is treated by surgery seems to be an inadequate wide margin. These findings are obtained from analysing the therapeutic results of cases involving surgical procedures adopting the concept of curative wide resection (using barriers). Therefore, the choice of any safety margin that is less than a curative wide margin should ensure as much margin as possible.

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