ORIGINAL ARTICLE

Classification of complications after progressive long bone lengthening: Proposal for a new classification

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Accepted: 7 May 2012

KEYWORDS
Bone lengthening; Long bone; External fixation; Intramedullary lengthening nail; Complications

Summary
Introduction: Long bone lengthening surgery using progressive surgical methods has been the source of frequent complications. Some authors have classified these complications either descriptively, according to the date of onset after the operation, or based on their severity. The Caton classification (1985) has had the virtue of contributing the notion of the treatment contract stipulating the objective to reach in treatment. Within the context of the preoperative information delivered to patients and their family, this contract can be improved by adding a notion of maximum treatment duration. The objective of this study was therefore to propose a classification that includes honoring a triple contract associating the planned gain in bone length, the duration of treatment, and the occurrence of sequelae.

Materials and methods: The classification of complications proposed includes four grades: grade I: triple contract honored, including a few treatments without general anesthesia; grade II: triple contract fulfilled, but with unplanned interventions under general anesthesia; grade III: the time stipulated was not honored because the time to obtain bone union was too long or because the program was interrupted; grade IV: sequelae are present. This classification was assessed based on a consecutive series of 34 surgical procedures in 32 patients (two patients underwent two lengthening procedures during this period) at 43 bone segments associating progressive lengthening with external fixation or with nail lengthening. The grade of each complication was determined by each of the authors according to the classification proposed and other classifications reported in the literature (Caton, Paley, Popkov, and Donnan).

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doi:10.1016/j.jotsr.2012.05.010
Results: Approximately one-third (10) of the 34 lengthening procedures did not present any complications. Two-thirds (24) presented 30 complications. Consensus was obtained between all the authors on the grades proposed for our classification and the Caton classification, but consensus was not reached with the other classifications in which part of the interpretation was subjective (Paley, Popkov, and Donnan).

Discussion: The classification proposed required respecting predetermined objectives during limb lengthening surgery based on a triple contract: gain, duration, and function. It is reliable and reproducible by different operators because the criteria are objective. It can also be applied to diverse surgical techniques, whether with external fixation and/or internal osteosynthesis.

Level of evidence: Level IV: retrospective study or historical series.

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Introduction

Long bones are progressively lengthened using a circular external fixator [1–6] or a unilateral external fixator [7,8], or with internal osteosynthesis of the intramedullary type [9–12] or screw and plate fixation [13]. The occurrence of complications is very frequent, so much so that to reduce the number of complications, surgical modifications and adaptations have been suggested, including rigid [14–19] or flexible [20–24] intramedullary nailing used in association with fixation. At the same time, these surgical techniques originally applied to unilateral bone lengthening were used for bilateral lengthening in small patients [25–27]. Despite these improvements, complications continued to occur; several can occur in the same patient, such that the complication rate can easily surpass 100%. These diverse complications have been collected by a number of authors [25,28–35]. However, the heterogeneity of the surgical techniques makes it difficult to compare the results of the different series.

It seems useful to separate patients who have not had complications from those who have had complications. Patients expect improvement in function and their general condition from these complex surgeries. It is therefore important to determine the percentage of patients with no complications for a given method.

As for the complications, most of the currently available classifications take function and any occurrence of sequelae into account [25,26,28–35]. The concept of a contract to fulfill was developed by Caton with the main criterion being the projected gain in limb length [25]. This contract can be improved by adding the respect of a projected duration of treatment including the lengthening and fixation periods [31]. This time item corresponds to either the duration of external fixator wear or the time until total weightbearing with internal osteosynthesis. The healing index (HI) defined by Aldegheri et al. [7], is expressed as the number of days by the number of centimeters gained and can be applied to the notion of duration defined above. If the patient is prepared to accept major treatment for a finite period of time, simply prolonging treatment to achieve bone union is in itself a complication that has not been clearly taken into account in the published classifications.

The objective of this study was to validate a single classification for all bone elongation systems based on the criteria of a triple contract: gain in correction, projected treatment duration, and maintenance of musculoskeletal system function. The duration of treatment to obtain bone regenerate corresponds to the external fixator removal date or the date total weightbearing is authorized for an internal osteosynthesis system; an HI equal to 45 days/cm is a maximum limit that should be retained to qualify bone treatment time. Finally, locomotor system function should not be worsened compared to the earlier condition.

The validation of this classification is based on the study of a consecutive series of 34 surgical bone elongation procedures in 32 patients (two patients had two consecutive lengthening procedures during the study period) who had undergone surgery on 43 bone segments.

Material and methods

Classification proposed

Respecting a triple contract has led us to suggest a classification of complications in four grades (Table 1):

- grade I: the triple contract is fulfilled, procedures are undertaken under local anesthesia and/or medical treatments are necessary but no intervention under general anesthesia is undertaken;
- grade II: the triple contract is also fulfilled but unscheduled intervention(s) under general anesthesia are necessary. These procedures can take place before the end of the lengthening program (grade II-a) (Fig. 1) or after the end of this program (grade II-b) without changing the date of external fixator removal or the date of total weightbearing;
- grade III: pursuing treatment is necessary beyond the planned period to obtain bone union, but at term, no alteration of function is observed. The HI is therefore lengthened with the external fixator removal or total weightbearing delayed beyond the scheduled time. In grade III-a, the length gain is greater than or equal to 75% of the initial objective (Fig. 2), whereas a gain less than 75% is classified as grade III-b. It is possible in grade III-b that bone union takes place within the normal time delay with a HI less than 45 days/cm, but since the scheduled correction has not been obtained, the patient who
procedures (five femurs and two tibias), one ilizarov fixator, and 35 TSF® fixators. Elastic stable intramedullary nailing (ESIN) [22–24] was used in 32 cases in association with TSF®. The associated deformities were progressively corrected at the same time as the lengthening.

The etiologies of the bone anomalies treated are reported in Table 2.

The mean gain in length obtained for the external fixator elongation procedures was 4.5 (±0.31) cm, with a mean HI of 23.7 (±1.7) days/cm. For the seven lengthening procedures using ISKD® nailing, the mean lengthening was 4.1 (±1.3) cm and total weightbearing was obtained 107.4 (±28.77) days after the date of surgery, for a HI equivalent to 27.4 (±6.36) days/cm. The follow-up period after removal of the external fixator was 2 to 4.5 years. The mean follow-up for the patients undergoing a nailing procedure was 3.6 years.

**Methods**

The number of surgical procedures that presented no complications was recorded. For the others, the grade and number of complications per procedure were reported.

Each of the authors of this study individually determined the grade of these complications using five classifications: the one reported herein and the Caton [28], Paley [29], Popkov [30], and Donnan [31] classifications. To define the grade of the complications per patient, the grade retained was the grade that corresponded to the most severe complication. Consensus or differences on the grades proposed for each complication and each classification were determined in a consensus meeting.

Complications were also studied according to the number of segments operated: one segment, two segments, two ipsilateral segments, or bilateral interventions. The following groups were also distinguished: lengthening using an external fixator and lengthening using an ISKD® nail. Percentages of complications were thus calculated for the patients and each procedure.

Correlations were determined between age, the gain achieved, and the HI with regard to the occurrence of complications.

**Statistical analysis**

The descriptive statistics present the mean and standard deviation. To compare the groups of limb lengthening using an external fixator or ISKD nailing, we used the Student t test and the Wilcoxon rank sum test for independent samples. The P-value less than 0.05 was considered clinically
Table 2  Etiology of cases treated.

<table>
<thead>
<tr>
<th>Etiology</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congenital anomaly</td>
<td>13</td>
</tr>
<tr>
<td>Post-traumatic lesions</td>
<td>4</td>
</tr>
<tr>
<td>Enchondromatosis (Ollier disease)</td>
<td>4</td>
</tr>
<tr>
<td>Congenital leg pseudarthrosis</td>
<td>1</td>
</tr>
<tr>
<td>Septic arthritis sequelae</td>
<td>1</td>
</tr>
<tr>
<td>Achondroplasia</td>
<td>1</td>
</tr>
<tr>
<td>Hypochondroplasia</td>
<td>1</td>
</tr>
<tr>
<td>Exostosis disease</td>
<td>1</td>
</tr>
<tr>
<td>Polyostotic fibrous dysplasia</td>
<td>1</td>
</tr>
<tr>
<td>Spondyloepiphyseal dysplasia</td>
<td>1</td>
</tr>
<tr>
<td>Turner syndrome</td>
<td>1</td>
</tr>
<tr>
<td>Angiomasitosis</td>
<td>1</td>
</tr>
<tr>
<td>Poliomyelitis sequelae</td>
<td>1</td>
</tr>
<tr>
<td>Cerebral palsy</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
</tr>
</tbody>
</table>

significant. The correlation between certain parameters (age, percentage of length gained, and the HI) was evaluated using the Bravais-Pearson coefficient. The AtteStat® software was used.

Ethics

The study was conducted in accordance with the national ethics guidelines of the Committees for Clinical Research on Human Subjects and in accordance with the 1975 Declaration of Helsinki revised in 2000.

Results

No complications were reported in 10 of 34 lengthening procedures (29.4%), slightly less than one-third of the cases.

Figure 3  Grade IV-a complication: 5-year-old boy, external longitudinal ectromelia, lengthening of the tibia, posterior subluxation of the knee (a). Correction using a new external fixator during femur lengthening. Result: knee flexion limited to 40° (b).

With regard to the 43 segments operated, 18 segments (41.9%) presented no complications. During the 24 other lengthening procedures, there were 30 complications on 25 bone segments. Of these 30 complications, there was one complication for 20 segments and two complications for five segments.

Table 3 describes the distribution of the complications according to the surgical sites and the implants used during the procedures. The subgroup presenting the highest

Figure 2  Grade III-a complication: Female, 27 years old, hemihypertrophy, lengthening of the tibia with TSF®. At 6 months, absence of bone regenerate (a). Bone union after bone grafting and screw and plate fixation (b). Result at 2 years (c).
number of complications according to the pathology comprised the patients operated on bilaterally for small size; depending on the surgical technique, the ISKD® subgroup presented the greatest number of complications, without, however, resulting in sequelae. Table 4 reports the number and percentage of complications per procedure exclusively presenting complications. For two-thirds of the procedures with complications, the mean complication rate was 125%.

The 30 complications in 24 procedures are reported in Table 5 and are distributed by procedure according to our classification depending on whether the triple contract was fulfilled:

- grade I was observed for eight procedures requiring simple acts in consultation with no general anesthesia and/or medical prescriptions;
- grade II-a involved five procedures that required surgical treatment before the end of the lengthening and fixation periods;
- grade II-b was observed in one case in which surgery after the end of the lengthening program nonetheless allowed the triple contract to be met;
- in the nine grade III-a cases, treatment was pursued beyond the projected duration, with function preserved;
- grade III-b: not observed;
- one grade IV-a case involved subluxation of the knee. The planned bone correction was nonetheless obtained;
- grade IV-b: not observed.

In Table 5, these 30 complications were also graded on the other classifications available [28–31].

A consensus was reached between the authors of this study for grading the complications on our classification and the Caton classification [28]. However, differences were observed with the other classifications [29–31] because of sometimes subjective interpretations.

As for the correlation between patient age and HI, we recorded a weakly positive trend ($r=0.345$). This trend showed an increase in the occurrence of complications with the increase in age of the patients treated.

The correlation between gain in length (%) and the HI was weakly negative ($r=-0.478$). We found no significant difference in HI between the external fixator or ISKD® nail lengthening ($P=0.058$).

### Table 4 Number and percentage of complications in relation to the surgical procedures followed by complications.

<table>
<thead>
<tr>
<th>Number of procedures</th>
<th>Number of complication</th>
<th>% complication per patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical site</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single segment</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Femur + tibia</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Bilateral</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Implants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External fixator</td>
<td>19</td>
<td>23</td>
</tr>
<tr>
<td>ISKD® nailing</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

### Discussion

The main classifications of complications are the Caton classification in France, published in 1985 [28] and then following the SoFCOT conference in 1990 [25], the Paley classification in the United States in 1990 [29], the Popkov classification in Russia in 1991 [30], and more recently the Donnan classification in Australia [31].

For Caton [25,26], the complications are minor, intermediate, and major or distributed into three categories:

- category I groups "subjects who present no complications or minor complications healed at the end of the lengthening procedure’’;
- category II includes “complications with the addition of a surgical procedure that was not planned in the initial strategy, whether they left no or few sequelae, with the lengthening program followed”;
- category III concerns “generally major complications leaving sequelae at the end of the lengthening procedure and/or the lengthening program not respected”.
<table>
<thead>
<tr>
<th>Complications</th>
<th>Treatment</th>
<th>Number</th>
<th>Caton</th>
<th>Paley</th>
<th>Popkov</th>
<th>Donnan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grade I: gain, HI, and function fulfilled – intervention without GA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local infection with pins or wires</td>
<td>Local care ± per os antibiotic therapy</td>
<td>2</td>
<td>I</td>
<td>Problem</td>
<td>Minor</td>
<td>I</td>
</tr>
<tr>
<td>Paresthesia, temporary paralysis</td>
<td>Surveillance, removal of wire in contact, no GA</td>
<td>4</td>
<td>I</td>
<td>Problem</td>
<td>Minor</td>
<td>I</td>
</tr>
<tr>
<td>Threat of early bone union</td>
<td>Acceleration of elongation speed</td>
<td>2</td>
<td>I</td>
<td>Problem</td>
<td>Minor</td>
<td>I</td>
</tr>
<tr>
<td>Delay in appearance of bone regenerate</td>
<td>Slowing down of elongation speed</td>
<td>1</td>
<td>I</td>
<td>Problem</td>
<td>Minor</td>
<td>I</td>
</tr>
<tr>
<td>Migration of ESIN</td>
<td>Percutaneous nail pushing, no GA</td>
<td>1</td>
<td>I</td>
<td>Problem</td>
<td>Minor</td>
<td>I</td>
</tr>
<tr>
<td><strong>Grade II-a: gain, HI, and function fulfilled - intervention with GA before end of lengthening program</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migration of ESIN nails</td>
<td>Cutting, nail pushing or early removal of ESIN nails</td>
<td>3</td>
<td>II</td>
<td>Obstacle</td>
<td>Intermediate</td>
<td>II</td>
</tr>
<tr>
<td>Problems with EF: deviation of assemble, cutaneous contact, instability</td>
<td>Revision of EF with GA</td>
<td>1</td>
<td>II</td>
<td>Obstacle</td>
<td>Intermediate</td>
<td>II/III</td>
</tr>
<tr>
<td>Breakage of EF material, screws</td>
<td>Material removal with GA</td>
<td>1</td>
<td>II</td>
<td>Obstacle</td>
<td>Intermediate</td>
<td>II</td>
</tr>
<tr>
<td>Blockage of lengthening nail</td>
<td>Movement in rotation with GA</td>
<td>1</td>
<td>II</td>
<td>Obstacle</td>
<td>Intermediate</td>
<td>II</td>
</tr>
<tr>
<td>Early union of regenerate</td>
<td>New osteotomy</td>
<td>1</td>
<td>II</td>
<td>Obstacle</td>
<td>Intermediate</td>
<td>II</td>
</tr>
<tr>
<td>Infection of osteotomy hematoma</td>
<td>Surgical cleansing and antibiotic therapy</td>
<td>1</td>
<td>II</td>
<td>Obstacle</td>
<td>Intermediate</td>
<td>II</td>
</tr>
<tr>
<td><strong>Grade II-b: gain, HI, and function fulfilled - intervention with GA after the end of the lengthening program</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migration of ESIN nails</td>
<td>Early removal of ESIN nails</td>
<td>1</td>
<td>II</td>
<td>Minor complication</td>
<td>Intermediate</td>
<td>II/III</td>
</tr>
<tr>
<td><strong>Grade III-a: gain and function fulfilled, HI &gt; 45 days/cm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joint stiffness</td>
<td>Mobilization with G, tendon elongation</td>
<td>4</td>
<td>II</td>
<td>Minor complication/major with goal met</td>
<td>Intermediate/ major</td>
<td>III</td>
</tr>
<tr>
<td>Non-union</td>
<td>Surgical treatment</td>
<td>3</td>
<td>II</td>
<td>Major complication without goal met</td>
<td>Major</td>
<td>III</td>
</tr>
<tr>
<td>Fracture after EF removal</td>
<td>Immobilization cast or osteosynthesis</td>
<td>1</td>
<td>II</td>
<td>Minor complication/major with goal met</td>
<td>Intermediate/ major</td>
<td>III</td>
</tr>
</tbody>
</table>
### Table 5 (Continued)

<table>
<thead>
<tr>
<th>Complications</th>
<th>Treatment</th>
<th>Number</th>
<th>Caton</th>
<th>Paley</th>
<th>Popkov</th>
<th>Donnan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational mal-union</td>
<td>Osteotomy</td>
<td>1</td>
<td>II</td>
<td>Major complication with goal met</td>
<td>Major</td>
<td>III</td>
</tr>
<tr>
<td>Delay in bone union (nailing)</td>
<td>Compression of elongation site</td>
<td>1</td>
<td>II</td>
<td>Minor complication</td>
<td>Intermediate</td>
<td>III</td>
</tr>
<tr>
<td>Grade III-a: function fulfilled, gain not obtained, HI &gt; 45 days/cm</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade IV-a: function not fulfilled (sequelae), gain obtained</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior knee subluxation</td>
<td>Secondary progressive correction with EF</td>
<td>1</td>
<td>III</td>
<td>Major complication without goal met</td>
<td>Major</td>
<td>IV</td>
</tr>
<tr>
<td>Grade IV-b: function not fulfilled (sequelae), gain not obtained</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ESIN: elastic stable intramedullary nailing; EF: external fixator; GA: general anesthesia; HI: healing index.

Category I concerns both patients who presented no complications and patients who presented minor complications, which brings this classification close to an assessment of the results. Although the gain in length obtained is respected for all surgical systems considered, the duration of the treatment planned is not defined. Thus, a patient with no sequelae is graded in category II whether he underwent several interventions over several months or a single procedure at the beginning of the lengthening period.

Paley collected the complications for lengthening procedures according to the Ilizarov method [29]: "‘muscle contractures, joint luxation, axial deviations, nerve and vascular injuries, premature consolidation, delayed consolidation, nonunion, pin site problems, hardware failure, loss of length, refractures, joint stiffness’, and other problems, specifying the severity for each complication. He differentiated them into ‘problems’, ‘obstacles’, and ‘complications’:

- ‘problems’ are ‘fully resolved by the end of the treatment period by nonoperative means’;
- ‘obstacles’ are ‘fully resolved by the end of the treatment period by operative means’;
- ‘complications’ group everything that remains unresolved at the end of treatment, including minor and major complications, with major complications differentiated depending on whether or not the therapeutic goal was met.

Grading the level of severity of certain complications is at times difficult to reproduce. The minimal duration of treatment is not mentioned, whereas it can be particularly long.

For the Ilizarov technique, Popkov [30] differentiated osseous, articular, infectious, and neurovascular complications. He also classified them according to their severity into minor, intermediate, and major complications, with the latter including the absence of a gain in length and the occurrence of a complication after removal of the external fixator. Popkov also described situations in which surgical and technical errors could lead to a cascade of complications compromising the final result.

Donnan’s classification [31] includes four grades:

- grade I: ‘‘no long-term functional or anatomical significance, no surgery or anesthesia required’’;
- grade II: ‘‘anesthesia or operation to correct, but no long-term significance’’;
- grade III: ‘‘significant functional or anatomical problem which spontaneously improves or correctable by surgery’’;
- grade IV: ‘‘irremediable by conventional treatment’’.

The terminology of this classification makes it imprecise because of the subjective nature of certain elements such as the notion of ‘‘long-term significance’’ or ‘‘functional or anatomical problems’’. A notion of treatment duration is mentioned in the publication, but it is not inscribed in the classification, however.

Other authors have proposed a classification of results after surgical bone lengthening. Fadel and Hosny distinguished the results of bone lengthening into excellent, good, fair, and poor [5]. In some series, the number of complications is reduced to the number of patients or segments [27,29,35]. A chronological distinction makes it possible to distinguish complications occurring in the intraoperative period, during lengthening and then fixation periods, and during the follow-up of lengthening or correction [31]. However, most authors using the Ilizarov method speak of complications occurring during the fixator wear period and after its removal [26,28–30,34].

For internal osteosynthesis bone lengthening methods, no universal classification has been suggested.
We are aware of the limits of being able to classify complications in a universal manner after different interventions and differing osteosynthesis methods. Nevertheless, all these surgical methods have the same objective, i.e., the lengthening gain necessary within a reasonable time without deteriorating initial function. These three components are important for the patient and the family and should be considered for a complication-free result. First of all, the length of the elongation planned in the preoperative period should be respected within a margin that we consider reasonable of approximately 25%. Secondly, the therapy time to reach the desired goal should be defined; it corresponds to the HI and, in agreement with Donnan [31], the HI should be less than 45 days/cm for lengthening, with the end corresponding to the date of external fixator removal or the date of total weightbearing authorized for nailing lengthening procedures. Finally, preoperative joint function should be recuperated at the end of treatment with a follow-up of approximately 12 months after removal of the external fixator. Thus, a contract can be defined based on these three points: the gain desired obtained within a limited time delay with, at term, a minimum function preserved. This triple contract has defined our classification, based exclusively on measurable and reproducible criteria (Table 1).

As for the percentage of complications published in specific series of lengthening procedures, it is useful to express it in relation to the total number of patients included in the series and in relation to only those patients who presented complications. In the information provided to patients and their family, the percentage of patients with or without complications is important to mention.

Although this classification proposal is intended for limb lengthening methods, it is tempting to extrapolate it to certain complex bone corrections, three-dimensional, that can currently be treated with external fixators [36]. The results are currently provided as angle correction values [37] or in comparison with radiological normality criteria [38–40]. The notion of a triple contract could also be applied to these complex corrections.

The subjective criteria expressed by the patient should be taken into account to evaluate the treatments implemented: pain, the cosmetic aspect of the scars, the experience of the patient and family, the psychological repercussions, and the quality of life [33].

Conclusion

The classifications available in the literature incompletely express the success or failure of progressive long bone lengthening surgery. These classifications are difficult to reproduce when not used by their promoters. The notion of respecting a contract with the objective of obtaining a predetermined gain was initiated by Caton in this major functional surgery. This concept should be extended to other items: maximum therapeutic time to reach bone union and the expected objective should be defined; function at the end of treatment should be at least comparable to function at the anterior state, if not improved. The four-grade classification proposed in this study is founded on honoring this three-point contract. This classification is reproducible because it is based on objective criteria. Its use can make it possible to compare the series of progressive long bone lengthening treated with different surgical methods and to improve the therapeutic strategies.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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