Fracture Gap and Callus Area Delineation on Digital Radiogram Utilizing Modified Segmentation Algorithm

Wojciech Glinkowski 1,2,4, Jaroslaw Zylkowski 1,4
Chair and Department of Orthopedics and Traumatology of Locomotor System, Medical University of Warsaw, Poland 1
Department of Anatomy, Center of Biostucture, Medical University of Warsaw, Poland 2
II Department of Clinical Radiology, Medical University of Warsaw, Poland 3

1,4 Polish Telemedicine Society, Warsaw, Poland 4

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SUMMARY
The regenerating bone during fracture healing is usually assessed by observing standard plain radiographs but radiographic definition of union is still not well established. Almost all clinical studies utilize radiographic expertise. The end-point of fracture healing has to be defined properly to make accurate clinical decision. The aim of the study was to support fracture healing evaluation by use of supplemental tool for proper segmentation of fracture callus region for further analysis. We have modified the one of the bacterial colony growth like segmentation algorithm for proper delimitation of fracture gap and callus area on digital or digitalized X-ray of long bone fracture cases. Our modification concerns in distinction of two attack components. First component is local and depends on signal intensity in “attacking” pixel and its direct surroundings. Second component depends on mean intensity of signal detected in whole “colony” and “attacking” pixel. Segmentation starts from one or more reference points. The “x” and “y” coordinates are user defined. They are represented by known intensity of a signal (Ia). In that moment mean intensity in colony is computed (Ik) as well. “Colonized” points attack their neighboring points ((xn, yn) where x n e(x-1,x+2) и y n e(y-1,y+1) i n e N i y e N). The strength of attack is estimated using following algorithm:

1. Local attack component (Al):
(1) ∆Il=|Io-Ia|/∆Imax where: ∆Imax – maximal delta value of intensity
Io – intensity value in attacked point
Ia – intensity value in attacking point
Condition ∆Il ∈ (0,1), for points ∆Il ≠ (0,1), ∆Il=1.
Al=1-∆Il where: k – empirical factor of equation.
2. Colony attack component (Ak):
∆Ik=|Io-Ik|/∆Imax where:
Ik – mean signal intensity in whole colony.
Condition ∆Ik ∈ (0,1), for points ∆Ik ≠ (0,1), ∆Ik=1.
Ak=1-∆Ik
3. Attack factor is calculated:
(5) A=Al*Ak

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There is stored information about total strength of attack (SA) and id number of attacking colony (iKo) in matrix describing points. If iKo of attacked point is equal to iKa (id of attacking colony) then SA=SA+A. If iKo ≠ iKa then SA=SA-AandifSA<0thenSA~SAandiKa=iK.
IfSA≥TA(TA – minimal successful strength of attack) then the point is marked as colonized and in next cycle it will attack its neighbors. The loop repetition is set. Exit points depend on choice of segmentation control method:
1. in case of user independent method

1 INTRODUCTION
The regenerating bone during fracture healing is usually assessed by observing standard plain radiographs (1,2,3,4,5). The radiographic definition of union is still quoted in many studies. Accordingly to Wade and Richardson a few studies suggest accuracy of radiographic definition of union in fractures as limited for internally fixed or inaccurate in conservatively treated fractures. However, almost all clinical studies utilize radiographic expertise. The need for new reliable methods to evaluate fracture healing has been emphasized by several authors (1,5). The end-point of fracture healing must be defined properly to make accurate clinical decision. Knowing when a fracture has healed may rationalize and optimize patient’s treatment. The aim of the study was to support fracture healing evaluation by elaboration of supplemental tool for proper segmentation of fracture callus region for further analysis.

2 MATERIAL AND METHODS
We have modified the one of the bacterial colony growth like segmentation algorithm for proper delimitation of fracture gap and callus area on digital or digitalized X-ray of long bone fracture cases. Our modification concerns in distinction of two attack components. First component is local and depends on signal intensity in “attacking” pixel and its direct surroundings. Second component depends on mean intensity of signal detected in whole “colony” and “attacking” pixel. Segmentation starts from one or more reference points. The “x” and “y” coordinates are user defined. They are represented by known intensity of a signal (Ia). In that moment mean intensity in colony is computed (Ik) as well. “Colonized” points attack their neighboring points ((xn, yn) where x n e(x-1,x+2) и y n e(y-1,y+1) i n e N i y e N).

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1. no possibility of attack, that means:
   a) number of no colonized points is 0 or
   b) number of neighbor’s points for which calculated A > 0 is 0 or
   c) interruption by user is also available.

2. in user dependent method – release of mouse button.

3. RESULTS

Radiograms of long bones (humerus, forearm, femur, tibia) were selected for the study. Series of images of 10 fracture cases were used in a study. The algorithm has been tested on different X-ray images (DICOM files) (up to 1000 intensity levels) and standard graphical formats (jpeg, gif, tiff) (255 gray scale levels). In first step we had to estimate k-factors for equations two and four, \(\Delta I_{\text{max}}\) and TA. We have found empirically that the best results are achieved for k-factor of equation 2 remains within the range from 0.01 to 0.05 and for equation 4 within the range from 0.01 to 0.03. Greater values of k-factors speed up the algorithm but may cause over spread errors, particularly in equation nr 2. TA values usually lie within the range 0.5-1.0. Lower values of TA also speed up computation. But in the range 0.7-1.0 it does not cause significant errors in segmentation. TA values above 1.0 are acceptable but cause algorithm works slower and results are not much better. \(\Delta I_{\text{max}}\) was set to 0.5 of difference between maximal and minimal pixel value in whole image in most of our experiments. This difference was calculated automatically. Greater values more likely produce errors. Another problem appeared as the number of reference points from which segmentation starts. General rule was set to place these points in distance about 2 \(d\), where “\(d\)” represents width of the fracture gap. The greater distance may appear in the case of well defined gap borders. We have found that results of segmentation using developed algorithm in user-dependent time of segmentation method cover correctly expected region of gap or callus in almost all so called “clear” cases. In uncertain cases, when whole gap or callus can not be drawn easily from its view on X-ray presented algorithm helps to delineate correctly shape of the gap and callus in almost all cases. That requires lower values of k-factors and greater TA values. Presented algorithm has been developed primarily for two dimensional images. However, there is a possibility to utilize it as an evaluation method for 3D images.

4. DISCUSSION

A noninvasive method to assess the fracture healing may utilize digital radiography as well digitalized plain classic X-ray (1,4). During the process of bone healing, mineralization of the callus leads to higher bone density and bone mass of the callus tissue. However, a little objective data exists to explain how the radiographic appearance correlate with the quantitative strength of the newly formed bone within fracture gap (5). Quantification of fracture healing utilizing X-ray image was employed in several studies as a unique approach (1,2,3). Relative analysis of optical density of digitized radiograms was employed as a key approach for image analysis and RODIA system development (1,2,3). Relative approach to measurement of optical density allows applying it on standard, plain radiographs despite of X-ray exposition standardization (film quality, process of development, etc.). Final result of each analysis shows comparison of different fragments of the same X-ray. The value received at the end of analysis is not appointed and requires to be compared with previous analyses. The method allows an assessment of trend and rate of the process of fracture healing. An assessment utilizing relative way requires setting internal calibration based on establishing reference ODV ROI. Viewing of the series of consecutive, timely developed images and their ODV assessment in analogue locations makes the healing assessment available. This already described approach (3) may improve daily orthopaedic trauma practice assessment by experienced specialist and determine “healing” quantity and predict the bone union completion. That may enhance radiological quantization of fracture healing (2,3). Current approach considers callus formation and its contribution in bone healing. Periosteal forming callus is located outside the fracture gap. Its size depends on healing stage and movement within fracture site. Stiff bone junction produce no or very little external callus, moderate movement leads to prominent periosteal callus for-

![Fig. 1 Colored area of fracture callus determined by segmentation algorithm](image-url)
mation and extensive movement prevent callus to appear. Having some difficulties in determining callus area while assessing more detailed analysis for whole healing area, supplemental algorithm was developed. Utilizing previously developed tools the exact determination of callus area was not correctly achieved due to uneven and blurred bone edges and smooth callus transition into surrounding soft tissue. “Smooth transition” represents low callus-soft tissue ODV gradient that may remain observed on “soft technique” X-ray or plaster density seen on the image when patient immobilized. Modified “bacterial colony growth algorithm” has been used to determine the callus and fracture line areas. An algorithm differentiates them from surrounding bone (mostly compact bone). Fracture gap and callus areas were delineated successfully in analysed cases.

5. CONCLUSIONS
The clinical usefulness of the algorithm in process of numerical evaluation of long bone fracture healing requires further evaluation. During analysis of first simple cases we noticed positive correlation between computed relative factors of signal intensity in segmented regions with clinical findings. only statistical analysis of patient’s cohort may give us final answer about real and added value of presented algorithm in this subject. This is the next aim and step of our work. The definition of fracture union is important for each patient treated, and for research. Simple, unarmed evaluation of radiographs may not define union with sufficient accuracy in internally fixed fractures. The degree of callus formation and the rise of fracture line optical density may seriously influence on final diagnosis of union. Improvements in evaluation of the radiographic image may lead to greater clarity of fracture healing on plain radiographs. Due to requirements of the precise quantification method to indicate fracture healing progress presented above algorithms can be recommended. Precise determination of fracture callus area utilizing modified segmentation algorithm may help to draw its shape, and make it easy accessible for further optical density analyses. Usefulness of presented methods has to be evaluated by statistical analysis on large number of cases due to satisfactory results of preliminary study.

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REFERENCES

Corresponding author: Ass. Prof Wojciech Glinkowski, MD, PhD. Medical University of Warsaw, Poland. E-mail: w.glinkowski@teleorto.pl