Generalized Net Model of Proximal Humeral Fractures Diagnosing

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Abstract: *Proximal humeral fractures are common injuries and they occur primarily in older patients. They represent 5.7% of diagnosed fractures and are the third most common fracture pattern seen in elderly. Fractures of the proximal humerus usually occur after a high or low energy fall. Due to the variety of factors, which influence the classification, and the diagnosis of these fractures, early detection is the key factor for an appropriate treatment. Accordingly, in this study we present a successful example of Generalized Nets application in traumatology and propose a novel approach to timely detection and diagnosing of proximal humeral fractures.*

Keywords: *Proximal humeral fractures, Generalized nets, Diagnosing.*

Introduction

Diagnostic evaluation of proximal humerus fractures is critical in assessing effective treatment. The initial evaluation of a patient suspected of having proximal humeral fracture should begin with a detailed history of the mechanism of injury, clinical examination and a plan for image testing. Most patients with proximal humeral fracture present to an acute care facility with pain following trauma. Pain and loss of function with swelling of the involved extremity are the most common symptoms on initial presentation. Severe point tenderness over the fracture site can be found with palpation and caution should be used to prevent further damage at the fracture site. Swelling usually appears immediately about the shoulder and upper arm while ecchymosis generally appears 24-48 hours later. Bruise may spread to the chest wall, flank, and forearm. A thorough physical examination is the next step in the evaluation. Physical examination should inspect length differences between the affected and the contralateral limb, active and passive range of motion and any signs of deformities. Gross deformity of the shoulder or a pronounced subacromial sulcus may suggest an associated dislocation of the humeral head [5]. Special attention should be paid to examination for potential concomitant injuries to the elbow, forearm, and wrist. It is essential to determine the presence of any associated neurovascular injury such as brachial plexus, circumflex, suprascapular or long thoracic nerve injuries. After the patient's clinical status has been established and stabilized, X-ray examination of the injured shoulder is mandatory. A "trauma X-ray" series should be performed. This consists of a true anterorposterior (AP) view, an axillary lateral view, and a scapular Y view. At least two perpendicular X-rays (true AP and a scapular Y view) are necessary to identify the fracture type. Computed tomography (CT) scans are indicated in cases of clinically suspected vascular or neural lesions and

complex injuries. Numerous types of proximal humeral fractures may occur and various fracture classifications are used to guide treatment, estimate prognosis, and predict the risk of complications.

The most frequently used system for classification of proximal humeral fractures is the Neer's four-part system. The four-part classification reported by Neer [6, 7] in 1970 represents a four-segment classification that incorporates the concepts of displacement and vascular isolation of articular segment. This system groups each fracture by the number of fracture segments and describes the fractured anatomic segment as a part. The groups are: group I, nondisplaced fractures; group II, two-part fracture; group III, three-part fracture and group IV, four-part fracture. Regardless of the number of fracture lines present, a proximal humerus fracture is considered to be nondisplaced by Neer's criteria when plain radiographs reveal less than 1 cm of displacement and 45 degrees of angulation of any one fragment with respect to all others. Fracture patterns may occur in combination with a glenohumeral dislocation. Proper diagnosing and classification of these fractures is extremely important for prognosis and treatment. The objective of the present work is to propose a novel approach to timely detection and diagnosing of proximal humeral fractures using the apparatus of Generalized nets (GNs; see [1, 2]). GNs are chosen as they are proven as an apparatus proven for successful modeling of parallel and concurrent processes, developed as an extension of the concept of Petri nets and some of their modifications. GNs are here applied for the development of a GN-model, whose the most important component is the classification of the proximal humeral fractures that follows the Neer's concept. Proposed below GN-model is a representative of so called reduced GNs [2] – a special class of GNs, which do not have some of the components. The presented reduced GN-model has parallel features with previous models describing different processes and algorithms [4, 8-11], but it is the first one which highlights the diagnostic algorithm for patient suspected of having proximal humeral fracture and thus represents an application of GNs in traumatology.

Generalized net model of proximal humeral fractures diagnosing

The developed GN-model (Fig. 1) has 8 transitions and 29 places with the following meanings:

- Transition Z_1 represents the medical record of the patient.
- Transition Z_2 – the history of the patient, physical examination techniques and the laboratory testing.
- Transition Z_3 – the results from the X-ray.
- Transitions Z_4, Z_5 and Z_6 – the detailed evaluation of the X-ray images.
- Transition Z_7 – the results from the CT.
- Transition Z_8 – the final diagnosis.

The GN-model contains 6 types of tokens: α, β, μ, η, γ and φ. Some of the model transitions contain the so called "special place" where a token stays permanently and collects information about the specific parts of the diagnosing process which it represents as follows:

- In place l_3, token β – information for the medical record of the patient.
- In place l_7, token μ – results from the physical examination and laboratory testing.
- In place l_{12}, token η – results from the X-ray.
- In place l_{26}, token γ – results from the CT.
- In place l_{29}, token φ – results obtained from the diagnostic imaging.

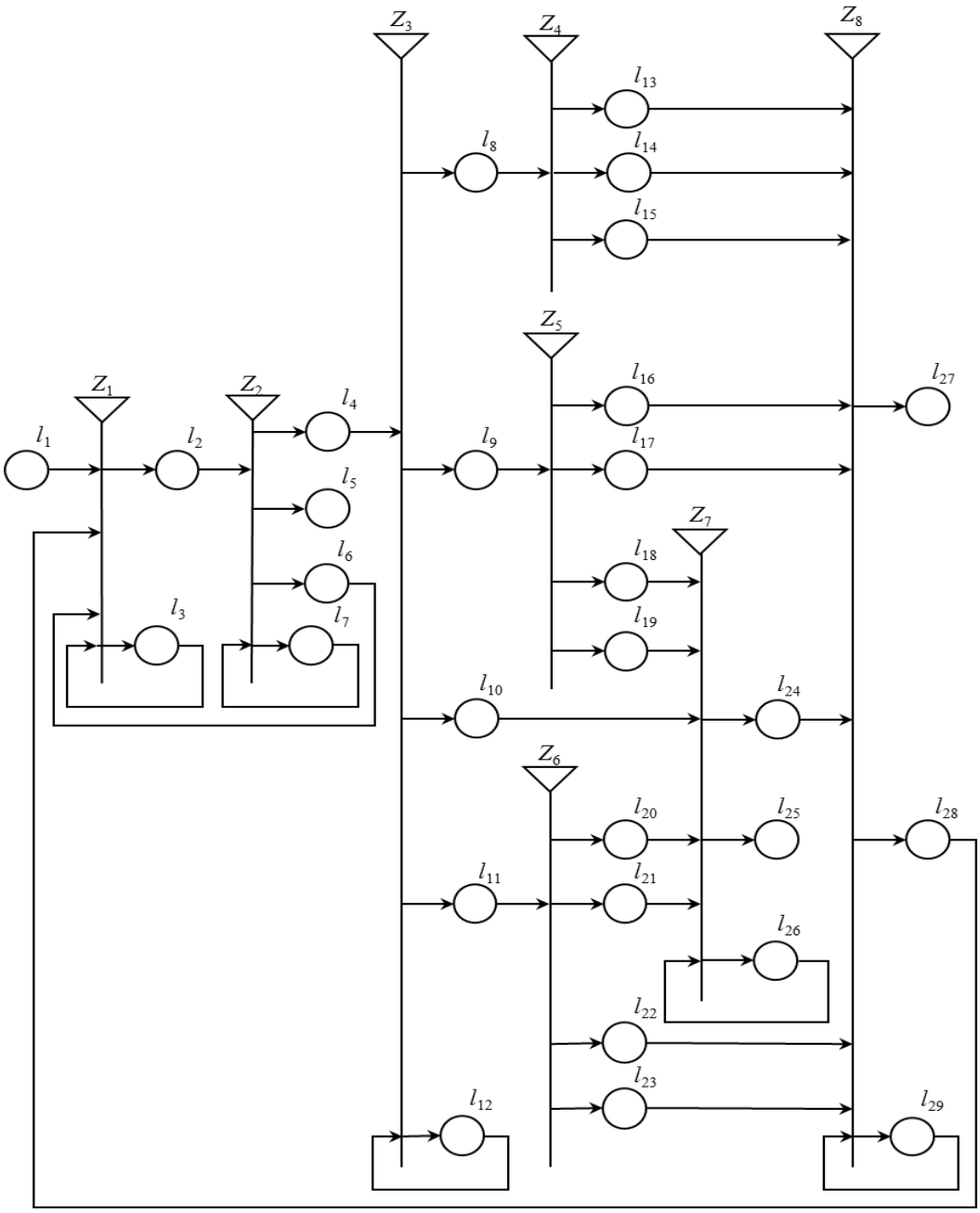

Fig. 1 Generalized net model of proximal humeral fractures diagnosing

The token α enters the net in place l_1 with an initial characteristic:

"*patient suspected of having a proximal humeral fracture*".

During the GN-model functioning, the α-tokens will unite with the tokens from the rest types (β, μ, η, γ, and φ). After that, some of these tokens can split in order to generate new α-tokens obtaining corresponding characteristics. When there are some α-tokens or β-tokens (α_1, α_2, α_3, α_4, β_1 and eventually β_2), on the next time-moment, all they will unite with a token from another type.

The transition Z_1 of the GN-model has the following form:

$$Z_1 = \langle \{l_1, l_3, l_6, l_{28}\}, \{l_2, l_3\}, \begin{array}{c|cc} & l_2 & l_3 \\ \hline l_1 & false & true \\ l_3 & W_{3,2} & true \\ l_6 & false & true \\ l_{28} & false & true \end{array} \rangle$$

and $W_{3,2}$ = "*medical history, physical examination and laboratory testing are necessary*".

The tokens from the four input places of transition Z_1 enter place l_3 and unite with token β with the above mentioned characteristic. On the next time-moment, token β splits to two tokens – the same token β and token α_1. When the predicate $W_{3,2}$ is true, token α_1 enters place l_2 and there it obtains a characteristic:

"*perform a detailed history of the mechanism of injury, physical examination and laboratory testing*".

The transition Z_2 has the following form:

$$Z_2 = \langle \{l_2, l_7\}, \{l_4, l_5, l_6, l_7\}, \begin{array}{c|cccc} & l_4 & l_5 & l_6 & l_7 \\ \hline l_2 & false & false & false & true \\ l_7 & W_{7,4} & W_{7,5} & W_{7,6} & true \end{array} \rangle$$

and,

$W_{7,4}$ = "*there are evidences of acute injury, severe pain, swelling in the shoulder region, significant limitation in both active and passive range of motion*";

$W_{7,5}$ = "$\neg W_{6,4} \wedge \neg W_{6,6}$";

$W_{7,6}$ = "*laboratory testing and physical examination have been applied on the patient*".

The tokens from the two input places of transition Z_2 enter place l_6 and unite with token μ with the above mentioned characteristic. On the next time-moment, token μ splits to three tokens – the same token μ and tokens α_1 and token β_1. When the predicate $W_{7,4}$ is true, token α_1 enters place l_4 and there it obtains a characteristic:

"*consider: fracture of the proximal humerus, send patient for X-ray examination*".

When the predicate $W_{7,5}$ is true, token α_1 enters place l_5 and there it obtains a characteristic:

"*rule out proximal humeral fracture*".

When the predicate $W_{7,6}$ is true, token α_1 enters place l_6 and it returns to place l_3 to extend the personal record of the current patient with characteristic:

"*results from the laboratory tests and physical examination*".

The transition Z_3 has the following form:

$$Z_3 = \langle \{l_4, l_{12}\}, \{l_8, l_9, l_{10}, l_{11}, l_{12}\}, \begin{array}{c|ccccc} & l_8 & l_9 & l_{10} & l_{11} & l_{12} \\ \hline l_4 & false & false & false & false & true \\ l_{12} & W_{12,8} & W_{12,9} & W_{12,10} & W_{12,11} & true \end{array} \rangle$$

and,

$W_{12,8}$ = "*the X-ray image shows: there is a visible fracture line in the articular segments of the humerus*";

$W_{12,9}$ = "*the X-ray image shows: there is a visible fracture line over the humeral shaft*";
$W_{12,10}$ = "$\neg W_{12,8} \wedge \neg W_{12,9} \wedge \neg W_{12,11}$" (no radiological evidence of fracture);
$W_{12,11}$ = "*the X-ray image shows: there is a visible fracture line over the tuberosities of the humerus*".

The tokens from the two input places of transition Z_3 enter place l_{11} and unite with token η with the characteristic, as mentioned above. On the next time-moment, token η splits to five tokens – the same token η that stays permanently in the place l_{11} and tokens α_1, α_2, α_3 and α_4.
When the predicate $W_{12,8}$ is true, token α_1 enters place l_8 and there it obtains a characteristic:
"*consider: fracture of the anatomic neck or fracture of the head of the humerus, proceed to detailed evaluation of the X-ray image*".
When the predicate $W_{12,9}$ is true, token α_2 enters place l_9 and there it obtains a characteristic:
"*consider: fracture of the surgical neck of the humerus, proceed to detailed evaluation of the X-ray image*".
When the predicate $W_{12,10}$ is true, token α_3 enters place l_{10} and there it obtains a characteristic:
"*send patient to CT*".
When the predicate $W_{12,11}$ is true, token α_4 enters place l_{11} and there it obtains a characteristic:
"*consider: fracture of the greater and/or of the lesser tuberosity of the humerus, proceed to detailed evaluation of the X-ray image*".

The transition Z_4 of the GN-model has the following form:

$$Z_4 = \left\langle \{l_8\}, \{l_{13}, l_{14}, l_{15}\}, \begin{array}{c|ccc} & l_{13} & l_{14} & l_{15} \\ \hline l_8 & W_{8,13} & W_{8,14} & W_{8,15} \end{array} \right\rangle$$

and,
$W_{8,13}$ = "*the fracture segment of the anatomic neck is displaced less than 1 cm with less than 45° angulation*";
$W_{8,14}$ = "*the fracture segment of the anatomic neck is displaced more than 1 cm with more than 45° angulation*";
$W_{8,15}$ = "*the articular surface is split into two or more fragments*".

When the predicate $W_{8,13}$ is true, token α_1 obtains a characteristic in place l_{13}:
"*one-part anatomic neck fracture*".
When the predicate $W_{8,14}$ is true, token α_1 obtains a characteristic in place l_{14}:
"*two-part anatomic neck fracture*".
When the predicate $W_{8,15}$ is true, token α_1 obtains a characteristic in place l_{15}:
"*humeral head split fracture*".

The transition Z_5 of the GN-model has the following form:

$$Z_5 = \left\langle \{l_9\}, \{l_{16}, l_{17}, l_{18}, l_{19}\}, \begin{array}{c|cccc} & l_{16} & l_{17} & l_{18} & l_{19} \\ \hline l_9 & W_{9,16} & W_{9,17} & W_{9,18} & W_{9,19} \end{array} \right\rangle$$

and,
$W_{9,16}$ = "*the fracture segment of the surgical neck is displaced less than 1 cm with less than 45° angulation*";
$W_{9,17}$ = "*the fracture segment of the surgical neck is displaced more than 1 cm with more than 45° angulation*";
$W_{9,18}$ = "*two fracture segments are displaced more than 1 cm with more than 45° angulation*";
$W_{9,19}$ = "*three fracture segments are displaced more than 1 cm with more than 45° angulation*".

When the predicate $W_{9,16}$ is true, token α_2 obtains a characteristic in place l_{16}:
"*one-part surgical neck fracture*".
When the predicate $W_{9,17}$ is true, token α_2 obtains a characteristic in place l_{17}:
"*two-part surgical neck fracture*".
When the predicate $W_{9,18}$ is true, token α_2 obtains a characteristic in place l_{18}:
"*three-part surgical neck fracture with one of the tuberosities*".
When the predicate $W_{9,19}$ is true, token α_2 obtains a characteristic in place l_{19}:
"*four-part surgical neck fracture with both tuberosities*".

The transition Z_6 of the GN-model has the following form:

$$Z_6 = \langle \{l_{11}\}, \{l_{20}, l_{21}, l_{22}, l_{23}\}, \begin{array}{c|cccc} & l_{20} & l_{21} & l_{22} & l_{23} \\ \hline l_{11} & W_{11,20} & W_{11,21} & W_{11,22} & W_{11,23} \end{array} \rangle$$

and,
$W_{11,20}$ = "*greater tuberosity and the humeral shaft are displaced with glenohumeral dislocation*";
$W_{11,21}$ = "*three fracture segments are displaced and the head of the humerus is driven down between the tuberosities*";
$W_{11,22}$ = "*the fracture segments of the tuberosities are displaced less than 1 cm with less than 45° angulation*";
$W_{11,23}$ = "*one of the fracture segments is displaced more than 1 cm with more than 45° angulation*".

When the predicate $W_{11,20}$ is true, token α_4 obtains a characteristic in place l_{20}:
"*three-part tuberosity fracture with posterior or anterior dislocation*".
When the predicate $W_{11,21}$ is true, token α_4 obtains a characteristic in place l_{21}:
"*four-part tuberosity fracture with valgus impaction*".
When the predicate $W_{11,22}$ is true, token α_4 obtains a characteristic in place l_{22}:
"*one-part tuberosity fracture*".
When the predicate $W_{11,23}$ is true, token α_4 obtains a characteristic in place l_{23}:
"*two-part tuberosity fracture*".

The transition Z_7 of the GN-model has the following form:

$$Z_7 = \langle \{l_{10}, l_{18}, l_{19}, l_{20}, l_{21}, l_{26}\}, \{l_{24}, l_{25}, l_{26}\}, \begin{array}{c|ccc} & l_{24} & l_{25} & l_{26} \\ \hline l_{10} & false & false & true \\ l_{18} & false & false & true \\ l_{19} & false & false & true \\ l_{20} & false & false & true \\ l_{21} & false & false & true \\ l_{26} & W_{26,24} & W_{26,25} & true \end{array} \rangle$$

and,
$W_{26,24}$ = "*the CT scan confirms the result from the X-ray*";
$W_{26,25}$ = "*the CT scan shows no indications of proximal humeral fractures*".

The tokens from all input places of transition Z_7 enter place l_{26} and unite with token γ with the characteristic, as mentioned above. On the next time-moment, token γ splits to three tokens – the same token γ that stays permanently in the place l_{25} and tokens α_1 and α_2. When the predicate $W_{26,24}$ is true, token α_1 enters place l_{24} and there it obtains a characteristic:

"*the exact morphology of the proximal humeral fracture, the degree of comminution and the size of the fractured fragments, associated tissue damages*".

When the predicate $W_{26,25}$ is true, token α_2 enters place l_{25} and there it obtains a characteristic:

"*consider: scapular, cervical spine, or other upper extremity injury*".

The transition Z_8 of the GN-model has the following form:

$$Z_8 = \langle \{l_{13}, l_{14}, l_{15}, l_{16}, l_{17}, l_{22}, l_{23}, l_{24}, l_{29}\}, \{l_{27}, l_{28}, l_{29}\},$$

	l_{27}	l_{28}	l_{29}
l_{13}	*false*	*false*	*true*
l_{14}	*false*	*false*	*true*
l_{15}	*false*	*false*	*true*
l_{16}	*false*	*false*	*true*
l_{17}	*false*	*false*	*true*
l_{22}	*false*	*false*	*true*
l_{23}	*false*	*false*	*true*
l_{24}	*false*	*false*	*true*
l_{29}	$W_{29,27}$	$W_{29,28}$	*true*

$\rangle$

and,

$W_{29,27} = W_{29,28}$ = "*the X-ray and the CT images are completely analyzed and the diagnosis is completed*".

The tokens from all input places of transition Z_8 enter place l_{29} and unite with token φ with the characteristic, as mentioned above. On the next time-moment, token φ splits to three tokens – the same token φ that stays permanently in the place l_{29} and tokens α and β. When the predicate $W_{29,27}$ is true, token α enters place l_{27} and there it obtains a characteristic:

"*the final diagnosis of the patient is: proximal humeral fracture of a certain type*".

When the predicate $W_{29,28}$ is true, token β enters place l_{28} and it returns to place l_3 to extend the personal record of the current patient with the characteristic:

"*the final diagnosis of the patient is: proximal humeral fracture of a certain type*".

When running the developed model with real patients' data, the obtained results may be analyzed by the recently proposed approach of intercriteria analysis [3]. As a multicriteria multiobjective decision making approach, it will permit discovery of new relations as well as improvement of the model accuracy as it has been proven yet in medical object [12].

Conclusion

The developed GN-model provides a framework that may be very useful for the primary care practitioners to guide diagnostic processes for patient suspected to have fracture of the proximal humerus. The proposed model is the first step to some further extensions with including of more detailed physical and neurological examination, making it possible to take into account much more complex modeling and improvement in decision making during the diagnostic processes.

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