Diagnostic System of Carpal Tunnel Syndrome with two kinds of layers to detect the syndrome and classify the grades based on clinical indicators

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Abstract: Diagnosis is essential for patient treatment. The diagnosis has two objectives: deciding on the disease or syndrome and classifying its grade, in which some fuzziness of diagnosis is imbedded. The purpose of this paper is to examine the relationship between the decision of disease or syndrome and the classification of grades. To clarify the fuzziness of diagnosis, we analyzed clinical data on patients with Carpal Tunnel Syndrome (CTS) using multivariate analysis. From the analytical results, we propose a new diagnostic logic with two diagnostic layers: A first layer for the detection about CTS by the clinical indicators such as Ring finger sensory splitting and Phalen’s test, and a second layer for the classification of CTS by indicators of Thenar muscle atrophy and Pinch disturbance.

Keywords Diagnostic Logic, Diagnostic Layers, Fuzziness of diagnosis, Carpal Tunnel Syndrome, Multivariate Analysis

1. Introduction

Accurate medical diagnosis is very important for patient treatment. In the medical diagnosis, medical doctors or surgeons use the patient’s information as clinical indicators for the diagnosis of deciding on disease. However, medical doctors or surgeons also pay attention to the medical treatments such as good choice of cure or surgery considering to the classification of the grades of disease. Therefore medical doctors have two kinds of goals of diagnosis; decision of disease and classification of its grades.

It is reasonably considered that the clinical indicator assigning to the severe stage of the disease can probably detect the decision of the disease. However, if this clinical indicator assigning to the severe stage is not effective to the decision about the disease, what is proper for the diagnostic logic of this disease? It is a new problem to discuss the diagnostic logic related with the decision of disease or syndrome and classification of its grades.

The framework of medical diagnosis is to connect the information of the patient X such as clinical indicators of pain, with the outcome of diagnosis Y such as cancer. The information about patient X is made up of a set of clinical indicators of $X_1$, $X_2$, $\cdots$, $X_m$. The outcome in the decision about disease is mainly divided into two groups, such as Cancer or Non-cancer. For a description of the diagnosis, we give an equation for the relationship as follows:

$$Y = \gamma(X_1, X_2, \cdots, X_m)$$

There are various methods for diagnosis including (1) by Tree type of decision making system, (2) by multivariate analysis and (3) by Fuzzy inference and so on.

(1) For the method by the Tree type of decision making
system: As a first step, the important indicator $x(1)$ is selected and if $x(1)$ is checked as (+), then we go to decide and if $x(1)$ is checked as (−), then we go to the next step with the indicator $x(2)$. The diagnostic system using tree-type decision-making makes progress towards the goal of diagnosing the disease by sequential decisions.

(2) For the method by multivariate analysis: By the method of multivariate analysis, the weight or score of each indicator can be calculated. The outcome is evaluated from the total score which is the linear combination of the score of each indicator [1], [2].

(3) For the method by Fuzzy inference: The total value for the diagnosis is calculated by the central point of the Fuzzy set composed of the union set of based membership functions for each indicator with the fuzziness of medical information [3], [4], [5], [6]. Fuzzy theory proposed by L. A. Zadeh[7] provided a new direction to find the fuzziness of phenomena and mechanisms and to develop many new methods such as fuzzy inference and fuzzy control.

We describe the diagnosis from two sides of $Y$ and $X$. As the outcome $Y$, medical doctors or surgeons have the two kinds of goals of the decision of the disease and the classification of the disease’s grades for the good choice of cure or surgery.

On the other hand, for clinical indicators $X$, some may correspond to detection of the disease, while others may correspond to the classification of grades and some to both detection and classification. The clinical indicators of patient’s information are then changed to a mixture of effective indicators about the decision on disease, those of classification, and those connected with both decision and classification.

The diagnostic system may be changed to correspondence or mapping from the multiple input $X$ of clinical indicators with including with indicators for decision and for classification into the multiple output $Y$ of the outcome set of the decision for $Y_0$ (Non-disease), and $Y_1$ (disease) and the set of classification of grades for $Y_{11}$ (Disease-Mild stage), $Y_{12}$ (Disease-Moderate stage) and $Y_{1N}$ (Disease-Severe stage). Input $X$ has the mixture of decision and classification and output $Y$ has two kinds of goals of decision and classification. The diagnosis and classification of grades may not belong to the same diagnostic logic. This is an aspect of the fuzziness of medical diagnosis.

In this paper, we discuss on the diagnostic logic of a concrete example about the diagnosis of Carpal Tunnel Syndrome (CTS) [8], [9], [10]. CTS is the syndrome caused by the damage of the median nerve which is important for the function of hands and upper extremity. For the diagnosis of CTS, we analyzed the CTS data by multivariate analysis to clarify the relationship between the decision and the classification of its grade.

Introducing two diagnostic aspects for a decision and classification of its grade about the CTS, we extract a subset of effective indicators for a decision on CTS and another subset of effective indicators for classification.

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![Fig. 1. The diagnostic system from clinical indicators for the outcome of diagnosis for Carpal Tunnel Syndrome](image-url)
2. Patients and Methods

This study included 755 hands of outpatients admitted to the orthopedics unit of Kasaoka Daiichi Hospital from October 2009 to September 2010. Their clinical fingers and hands were checked according to the Japan Orthopedic Association criteria, and 507 hands were diagnosed as CTS (male 127: female 380), while 248 hands were Non-CTS (male 66: female 182) by hand surgeon specialists. The clinical findings or indicators selected for diagnosis; Tinel's test, Phalen's test, Sensory disturbance, Ring finger sensory splitting, Thenar muscle atrophy, Pinch disturbance, and Distal motor latency, are shown in Fig. 1.

Moreover, the 507 hands diagnosed as CTS were also classified into three grades (Grade I: mild symptoms, Grade II: moderate symptoms and Grade III: severe symptoms according to Hirooka’s evaluation system [11]. There were 361 hands at Grade I, 37 hands at Grade II and 109 hands at Grade III out of the 507 CTS hands. Patient with the severe stage of CTS is needed by the surgery shown in Fig.2.

Clinical indicators (X₁, X₂, …, Xₘ) have two kinds of data, numerical data such as Distal muscle latency of (7.0 ms) and categorical data such as Sensory disturbance of (severe degree). The data of clinical indicators are mixed with numerical data and categorical data. In this paper, we change the numerical data of Distal motor latency into categorical data such as Distal muscle latency (−) when it is smaller than 4.2 ms, the other category is Distal muscle latency as (+).

All the cases decided as CTS or Non-CTS and as CTS grades were finally evaluated by the same doctor, Hiroyuki Hashizume, a specialist of hand surgery, in consultation with other doctors. The judgments were reexamined by the surgeries of patients with the severe or moderate stage of CTS needing surgery, and the judgments regarding the patients with moderate stage CTS, mild stage CTS or Non-CTS were reexamined at the second medical interview as outpatients six months after the first interview.

Statistical Methods

For statistical analysis, multivariate analysis (Quantification method II) was adopted in Fig. 3. The contribution of each clinical indicator to the diagnosis of CTS and the classification of the grade were evaluated as categorical scores by multivariate analysis. All statistical analyses were performed using Excel Quantification version 3.0 (Esumi Co., Tokyo, Japan). This study was approved by the Ethics Committee of Kasaoka Daiichi Hospital.

3. Results

We analyzed CTS data to examine the decision of CTS, the classification of its grade and the relationship between decision and classification.

We obtained the analytical results for the decision of CTS (Result 1; Result 1-1, 1-2 and 1-3), for the classification of CTS’s grades (Result 2) and for the relationship between the decision and classification by the particular indicators of Thenar muscle atrophy and Pinch disturbance (Result 3).

Result 1-1
(Decision of CTS on each indicator)

We obtained the analytical results about the decision on CTS (CTS or Non-CTS) based on each clinical indicator in Table 1.
Defining the probability of decision of CTS by (+) sign of each indicator as $P_1$ described as:

$P_1 = Pr \{ \text{Detecting CTS | by (+) sign of indicator} \}$

we obtained the values of $P_1$ as follows; $P_1$ (by (+) sign of Distal motor latency) = 478/507 (94.3%), $P_1$ (by (+) sign of Sensory disturbance) = 480/507 (94.7%), $P_1$ (by (+) sign of Pinch disturbance) = 319 (62.9%), $P_1$ (by (+) sign of Phalen’s test) = 437/507 (86.2%), and $P_1$ (by (+) sign of Tinel’s test) = 480 (94.7%).

On the contrary, we had the lower values of $P_1$ (by (–) sign of Pinch disturbance) = 117/507 (23.1%) and $P_1$ (by (+) sign of Thenar muscle atrophy) = 146/507 (28.8%).

Defining the probability of a decision of Non-CTS by the (–) sign of each indicator as $P_2$ described as:

$P_2 = Pr \{ \text{Detecting Non-CTS | by (–) sign} \}$

we obtained the values of $P_2$ as follows; $P_2$ (by (–) sign of Thenar muscle atrophy) = 247/248 (99.6%), $P_2$ (by (–) sign of Ring finger sensory splitting) = 246/248 (99.2%), $P_2$ (by – sign of Tinel’s test) = 245/248 (98.8%), $P_2$ (by (–) sign of Pinch disturbance) = 242/248 (97.6%), $P_2$ (by (–) sign of Phalen’s test) = 242/248 (97.6%) and $P_2$ (by (–) sign of Sensory disturbance) = 207/248 (83.5%).

As the candidates for effective indicators to decide CTS under the conditions of ($P_1\geq0.8$ and $P_2\geq0.8$), we can select Ring finger sensory splitting, Phalen’s test and Sensory disturbance.

![Diagram](image)

**Fig. 3. Procedures of statistical analysis of CTS data by multivariate analysis**

**Table 1. Prevalence of each clinical indicator in Carpal Tunnel Syndrome (CTS) and Non-CTS groups**

<table>
<thead>
<tr>
<th>Clinical indicators</th>
<th>CTS group n=507</th>
<th>Non-CTS group n=248</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring finger sensory splitting +</td>
<td>448 (88.4%)</td>
<td>2 (0.8%)</td>
</tr>
<tr>
<td>Phalen’s test +</td>
<td>437 (86.2%)</td>
<td>6 (2.4%)</td>
</tr>
<tr>
<td>Sensory disturbance +</td>
<td>480 (94.7%)</td>
<td>41 (16.5%)</td>
</tr>
<tr>
<td>Tinel’s test +</td>
<td>319 (62.9%)</td>
<td>3 (1.2%)</td>
</tr>
<tr>
<td>Thenar muscle atrophy +</td>
<td>146 (28.8%)</td>
<td>1 (0.4%)</td>
</tr>
<tr>
<td>Pinch disturbance +</td>
<td>117 (23.1%)</td>
<td>6 (2.4%)</td>
</tr>
<tr>
<td>Distal motor latency +</td>
<td>478 (94.3%)</td>
<td>119 (48.0%)</td>
</tr>
</tbody>
</table>

☆ high prevalence of positive and negative indicators (cut-off value is over 80%)
Result 1-2
(Decision of CTS by two indicators)

We examined the multiplier effects of two indicators to the decision of CTS selected among seven indicators. Focusing on the high percentage of detecting CTS, we chose one particular indicator of Ring finger sensory splitting with the highest percentage of detecting CTS from Table 1 and obtained the relationship between Ring finger sensory splitting and other indicators in Table 2.

In Table 2, the mark of (+, −) shows (+) sign of Ring finger sensory splitting and (−) sign of another indicator. We denote the percentage of detecting CTS by (+, +) as \(P^{**}(\text{CTS})\), and the percentage of detecting CTS by \({(+, +), (+, -), (-, +)}\) as \(P^{*}(\text{CTS})\). The indicators with the condition of the percentage of \(P^{**}(\text{CTS}) > 0.7\) and the percentage of \(P^{*}(\text{CTS}) > 0.7\) were the couple of (Ring finger, Phalen’s test), (Ring finger, sensory disturbance), and (Ring finger sensory splitting, Distal motor latency).

On the contrary, denoting the percentage of detecting Non CTS by (−, −) as \(P^{#}(\text{Non CTS})\), the indicators with \(P^{**}(\text{CTS}) > 0.7\), \(P^{*}(\text{CTS}) > 0.7\) and \(P^{#}(\text{Non CTS}) > 0.7\) were the couples of (Ring finger, Phalen’s test), (Ring finger, Sensory disturbance). This suggested that the indicators of Phalen’s test and Sensory disturbance were useful for detecting CTS with Ring finger sensory splitting. The results in Table 2 also might extract the candidates of useful indicators for the decision of CTS.

Result 1-3
(Decision of CTS by seven indicators)

Analytical results for discriminating between the CTS group and Non-CTS group based on the seven clinical indicators by the multivariate analysis were obtained in Fig. 4 and Table 3.

The categorical scores on the (+) sign and the (−) sign of each indicator were all characterized as the positive value (for CTS) by the (+) sign of the indicator and the negative value (for Non-CTS) by the (−) sign of the indicator. Analytical results of categorical scores of indicators showed the validity. The range of categorical scores on each indicator shows the weight of evaluation for discriminating CTS from Non-CTS. The range of Ring finger sensory splitting was 0.77, that of Phalen’s test was 0.66, that of Sensory disturbance was 0.55, that of Distal motor latency was 0.37 and that of Tinel’s test was 0.12, which were bigger than that of the other indicators. The range of indicators of Thenar muscle atrophy,
and Pinch disturbance were very small. These two indicators were eliminated from the analytical results by the method of increasing variables and decreasing variables of multivariate analysis.

The categorical scores in Fig. 4 suggested that the indicators of Ring finger sensory splitting, Phalen’s test, Sensory disturbance, Tinel’s test and Distal motor latency could be used as effective indicators for the first layer of diagnosis with the decision filter of CTS.

We also obtained the total evaluation for detection of CTS in Table 3. Table 4 showed the relationship between the outcomes of diagnosis by hand surgeon specialists and that by a new diagnostic system based on multivariate analysis. From Table 3, we have the sensitivity:

\[
\frac{(\text{Diagnosis as CTS by new system})}{(\text{Diagnosis as CTS by surgeonos})} = \frac{470}{507} = (92.7%)
\]

and the specificity:

\[
\frac{(\text{Diagnosis as Non--CTS by new system})}{(\text{Diagnosis as Non--CTS by surgeonos})} = \frac{244}{248} = (98.4%).
\]

Therefore, the new diagnostic system was reasonable for the discrimination of CTS.

**Result 2**

(Classification of CTS by multivariate analysis)

Analytical results for the classification of CTS’s grades by the multivariate analysis were obtained. We showed the categorical scores of indicators for classification between the grade(I+II) and (III) in Fig.5. The categorical scores of seven indicators also showed the reasonability.

From the analytical result, only two indicators of Pinch disturbance and Thenar muscle atrophy were mainly extracted. The indicators with bigger categorical scores were Pinch disturbance (range: 2.03) and Thenar muscle atrophy (range: 0.39), which could be candidates for effective indicators to classify the grade. These indicators for classification were different from the indicators for the decision of CTS.

We also showed the total evaluation for classification of grades in Table 4. From Table 4, we have the sensitivity:

\[
\frac{\text{(Classification of (I+II) by new system)}}{\text{(Classification of (I+II) by surgenosos)}} = \frac{389}{398} = (97.7%)
\]

and the specificity:

\[
\frac{\text{(Classification of (III) by new system)}}{\text{(Classification of (III) by surgenosos)}} = \frac{108}{109} = (99.1%).
\]

This result is reasonable for the classification of grades. Therefore, it is suggested that the clinical indicators of Pinch disturbance and Thenar muscle atrophy can be used as the effective indicators for the second layer with the classification filter of CTS’s grades.

We also obtained the characteristics of the indicators of Thenar muscle atrophy and Pinch disturbance in Table 1, which suggested that these two indicators had little chance to detect CTS, but could detect the severe stage of CTS in Fig.5.

![Table 1](image)

**Fig. 4.** Analytical results of categorical scores and range of clinical indicators for the decision of Carpal Tunnel Syndrome by the multivariate analysis
Table 3. The relationship between the outcomes of diagnosis of Carpal Tunnel Syndrome (CTS) by hand surgery specialists and those by a new diagnostic system using multivariate analysis

Table 4. The relationship between the outcomes of classification of the grades of Carpal Tunnel Syndrome (CTS) by hand surgery specialists and those by multivariate analysis

Result 3

(Characteristics of particular indicators)

The indicators of Thenar muscle atrophy and Pinch disturbance seemed to take a particular role for the detection of CTS and its classification.

We examined the effects by the indicators of Thenar muscle atrophy and Pinch disturbance concerning to the decision and classification.

For the indicator of Thenar muscle atrophy, we obtained the analytical results as the percentages of detecting CTS from the data of (Non-CTS and CTS) and classifying the grades of CTS from the data of CTS diagnosed by surgeons in Table 5. For the indicator of Pinch disturbance, we also obtained the analytical result in Table 6.

We compared two kinds of percentages for detecting CTS and classifying grades of CTS.

Table 5 on Thenar muscle atrophy showed that the (+) sign responses of Thenar muscle atrophy could detect the severe stage of CTS (CTS III) with a high percentage

\[
\frac{\text{+sign of theanar muscle atrophy}}{\text{CTS III}} = \frac{107}{109} = 98.2\%.
\]

On the other hand, the (+) sign of this indicator could detect CTS with a small percentage of 29% (146/507), though it could detect Non-CTS with the percentage of 99.5% (247/248) by the (–)sign. This is the reason that Thenar muscle atrophy could not become an

Sensitivity = \( \frac{470}{507} = 92.7\% \), Specificity = \( \frac{244}{248} = 98.4\% \)
After the decision of CTS (CTS III) with a high percentage Pinch disturbance could detect the severe stage of CTS. Thenar muscle atrophy. The (+) sign of effective indicator for detecting CTS.

Table 5 on Pinch disturbance showed similar characteristics as Thenar muscle atrophy. The (+) sign of Pinch disturbance could detect the severe stage of CTS (CTS III) with a high percentage

\[
\text{Pr (CTS by Pinch (+))} = \frac{108}{109} = 99.1\%.
\]

But it could not detect CTS with the percentage of 23.1% (117/507), which was small. This is the reason that Pinch disturbance also could not become an effective indicator for deciding CTS.

The indicators of Thenar muscle atrophy and Pinch disturbance seemed to take a particular role for the classification of the moderate or severe stage of CTS.

From the analytical results, we propose a new diagnostic logic with two diagnostic layers: A first layer for the decision about CTS by the clinical indicators of Ring finger sensory splitting, Phalen’s test, Sensory disturbance, Tinel’s test and Distal motor latency, and a second layer for the classification of CTS by the ways of Pinch disturbance and Thenar muscle atrophy in Fig. 6.

4. Discussion

Which clinical findings are effective to the diagnosis of the disease or syndrome? This is the primary question in the diagnosis.

Medical doctors or surgeons consider how to use the effective clinical indicators for diagnosis and for good choice of treatments, which means two kinds of objectives of acute diagnosis and suitable treatments. The diagnosis needs the decision of disease and classification of its grades.

It is casually considered that the clinical indicator assigning the severe stage of the disease could discriminate the disease from non-disease.
From the analytical results by multivariate analysis, we obtained the following:

(1) For the decision of CTS (about Result 1-1 and 1-3)

From Fig.4 and Table 3(Result 1-3), analytical results suggested that the indicators of Ring finger sensory splitting, Phalen’s test, Sensory disturbance, Tinel’s test, and Distal motor latency were useful to detect CTS. Table 1 also showed that the percentages of these indicators were high values. On the contrary, Fig.4 showed that the Indicators of Thenar muscle atrophy and Pinch disturbance were not useful to detect CTS. Table 1 also showed that the percentages by these two indicators to detect CTS were 28.8% and 23.1%, respectively. Therefore, the indicators of Ring finger sensory splitting, Phalen’s test, Sensory disturbance, Tinel’s test, and Distal motor latency were effective indicators to detect CTS.

(2) For the classification of CTS’s grades (about Result 2)

From Fig.5 and Table 4, analytical results suggested that indicators of Thenar muscle atrophy and Pinch disturbance were not useful to classify the grades. Therefore Pinch disturbance and Thenar muscle atrophy were not effective indicators for detecting CTS but effective indicators for classifying the CTS’s grades. The set of indicators for classification of CTS’s grades was different from the set of indicators for decision of CTS.

(3) Characteristics of particular indicators (about Result 3)

Table 5 and Table 6 showed the characteristics of particular indicators of Thenar muscle atrophy and Pinch disturbance. The indicators of Thenar muscle atrophy and Pinch disturbance were not effective indicators for detecting CTS but effective indicators for detecting the severe stage of CTS. That is, before the decision of CTS they were not effective indicators, but they were effective for classification after the decision.

We discuss on the diagnostic system from the two sides of indicators (X) and the output of diagnosis (Y). In the diagnostic system, it might be considered that if the degree of an indicator \( X_i \) is increasing from the non-reaction or mild degree to the severe degree, then the output \( Y \) is increasing from the Non-disease via the mild...
stage of disease to the severe stage of disease. In this case, we can arrange the states of Non-disease, Disease I (mild stage), Disease II and (moderate stage) and Disease III (severe stage) on the same diagnostic line or on the same diagnostic plane. That is, this diagnostic logic supports the hypothesis that the states of Non-Disease, Disease I, Disease II, and Disease III have some continuation.

From the analytical results, we propose that the diagnosis of CTS has two diagnostic layers for the diagnosis of CTS and for the classification of its grade.

At the first diagnostic layer, the diagnostic filter with the useful indicators such as Ring finger sensory splitting showed good results for the detection of CTS with a sensitivity of 92.7% and a specificity of 98.4%. At the second diagnostic layer, the classification filter of grades by the indicators such as Pinch disturbance also showed good results with the sensitivity of 97.7% and specificity of 99.1%.

All diseases or all syndromes may not have the diagnostic logic with layers, and we showed an example of the diagnosis with layer for Carpal Tunnel Syndrome. Analytical results by the multivariate analysis do not take account of the correlation of indicators. For examples, the multiplier effect of Phalen’s test and another indicator might influence the diagnostic result as Result 1-2. The multiplier effect of indicators will be our future research.

5. Conclusion

For the clarification of the fuzziness imbedded in the diagnostic system, we approached the diagnosis of Carpal Tunnel Syndrome (CTS) by the statistical method of multivariate analysis based on the clinical indicators. From the statistical analysis of CTS data, we obtained the following results. The diagnosis of CTS has two diagnostic layers for decision of CTS and for classification of its grade.

For the first diagnostic layer, the diagnostic filter with the useful indicators of Ring finger sensory splitting, Phalen’s test, Sensory disturbance, Tinel’s test, and Distal motor latency showed good results for the detection of CTS with the sensitivity of 92.7% and the specificity of 98.4%. At the second diagnostic layer, the classification filter of grades with the useful indicators of Pinch disturbance and Thenar muscle atrophy showed good results with the sensitivity of 97.7% and the specificity of 99.1%.

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