JOURNAL OF INFORMATION SCIENCE AND ENGINEERING 38, 463-477 (2022)
DOI: 10.6688/JISE.202203_38(2).0011

Automatic Classification of Uroflow Patterns via the Grading-based Approach

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Automatic classification of uroflowmetry curves into different patterns can help urologists to make an accurate diagnosis of the lower urinary track function in real time and increase the agreement of interpretation among urologists. In this paper, we propose a grading-based approach to the automatic classification of uroflowmetry curves by considering 87 cases of medical data, which are confirmed by the consensus of two highly experienced urologists. The interpretation of uroflowmetry is usually subjective and empirical. In this study, the same results identified by both urologists were 87 cases out of 160. To avoid the disadvantage of visual interpretation, our approach integrates the urologist's experiences and different weights for different conditions, including several new conditions, the raising angle and the number of significant drops. Moreover, the objective view of classification is useful for teaching urologists to watch for voiding dysfunctions. From our experimental study with statistical analysis comparing the results of our approach with two urologists' observations, we have shown that the agreement of normal / abnormal types is very good.

Keywords: classification, grading, urodynamic study, uroflow pattern, uroflowmetry curve

1. INTRODUCTION

Urodynamic study is the best diagnosis tool for lower urinary tract symptoms (LUTS) and the function of the bladder [1-5]. It can provide extremely valuable diagnostic data for

Received March 11, 2020; revised November 6, 2020 & January 3, 2021; accepted February 5, 2021.
Communicated by Tzung-Pei Hong.
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bladder dysfunctions [3]. Urodynamic tests can accurately measure the volume of the urine when the person urinates into the special container [6, 7]. The computer uses the data to generate and export a graph that shows the change in the flow rate (ml/sec) over time (sec), so the urologist can see when the flow rate is highest and how many seconds it takes to get there [8].

The interpretation of the uroflowmetry is important for evaluating voiding dysfunctions [9, 10]. Some urologists consider the maximum flow rate and the flow curve to be the most important factors for interpreting uroflowmetry [4]. In addition, the time to the maximum flow rate and the voided volume also have important reference value. All of the above parameters can be measured and used to quantify the uroflowmeter data except the flow curve, because the urine flow curve is difficult to interpret and classify. Therefore, in our study, we define two types (normal and abnormal) and six patterns of uroflowmetry (Bell, Tower, Staccato, Interrupted, Plateau and Obstructive). Fig. 1 shows the models of the six uroflow patterns. The *x*-axis in the uroflowmetry curve is the time in seconds, and the *y*-axis is the flow rate of urination in ml/sec. Only the Bell-shaped pattern shown in Fig. 1 (a) is regarded as the normal type [2, 8, 9, 11], and the other patterns shown in Figs. 1 (b)-(f) represent different lower urinary tract dysfunctions (LUTD) [11-13]. For example, for the Tower-shaped pattern shown in Fig. 1 (b), the suggestive LUTD is detrusor overactivity [7].

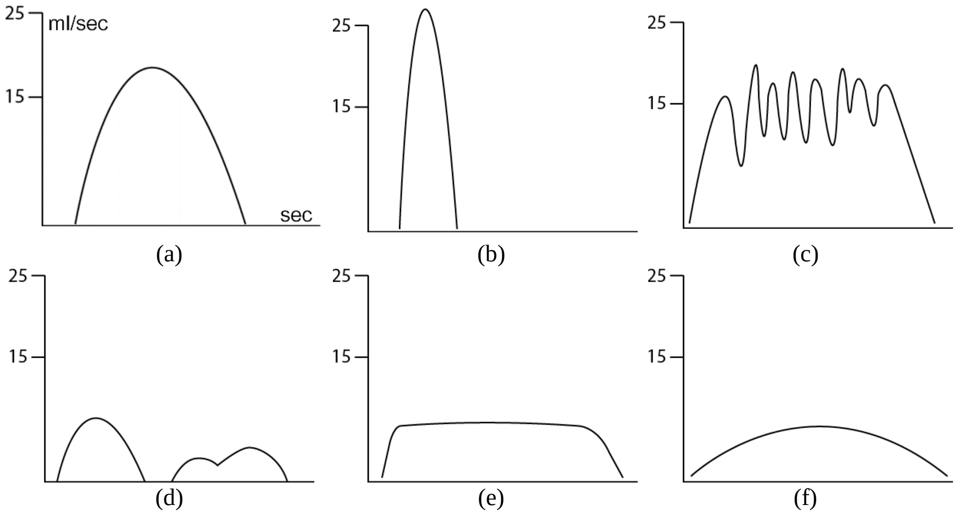

Fig. 1. Uroflow patterns: (a) Bell-shaped; (b) Tower-shaped; (c) Staccato-shaped; (d) Interrupted-shaped; (e) Plateau-shaped; (f) Obstructive-shaped.

Currently, urologists must look at the graph and consider many parameters to classify the type of uroflow pattern. They interpret the uroflowmetry after the computer outputs the graph with multiple parameters [14]. In fact, other computable values from the 2D-figure, like the angle along the curve, may be helpful for interpretation in addition to the standard parameters, like the peak flow rate and the voided volume. For some troublesome conditions that are difficult to interpret visually, like the flow rate reaching zero, the efficient and reliable computing power of the PC could provide assistance. Some useful formulas, like the flow index, could be analyzed by the PC in real time. Computers would also standardize the interpretation of the flow curve as each urologist has a different way of explaining them, so the results of interpretation of uroflowmetry may be inconsistent between urologists [8].

To help the experienced urologist teach urologists about interpreting voiding dysfunctions by making use of the computing power of the PC in real time, we propose a grading-based approach to the automatic classification of uroflowmetry curves. This approach considers several new parameters for the interpretation of flow curves, including the raising angle, the drop angle, the number of significant drops, and the total area of the small curves. We assign different grades to the different parameters and compute the total grade based on different weights for different conditions of different uroflow patterns. This allowed us to increase the accuracy of interpretation from an objective viewpoint and enhance the consistency between urologists, because the computing process of the computer is more efficient and reliable than visual interpretation. We clearly defined the interpretation of conditions of uroflow patterns, which will be useful in CAI (Computer-Assisted Instruction) [15-17]. From our statistical performance study, we showed that the agreement of normal/abnormal types between the proposed approach and the two urologists' observations is very good.

The rest of the paper is organized as follows. In Section 2, we present our proposed approach. In Section 3, we evaluate the performance of the proposed approach with the two urologists' same observations. Finally, in Section 4, we summarize conclusions.

2. THE PROPOSED APPROACH

In this section, we present a grading-based approach to classifying the uroflowmetry curves. Since our main concern is whether the pattern is normal or abnormal, we point out the different properties between the Bell-shaped pattern and each of the five abnormal patterns. There are several issues concerned in our approach. First, we have to confirm the diagnosed conditions for each pattern by discussing them with two urologists, Shei-Dei Yang, M.D. [18] and Yao-Chi Chuang, M.D. [19]. Both of them are experienced urologists specializing in urodynamics. Hereafter, we refer them as Dr. Yang and Dr. Chuang, respectively. Next, we have to decide the weight and grade for each pattern by repeatedly adjusting those values according to the given answer from the urologists. Then, due to the overlapping conditions among the patterns, we decide the order of the grading process and use the one with the highest grade as the final answer. To make sure that the urologist can precisely identify the pattern, we point out some avoidable mistakes with visual interpretation.

2.1 Conditions of Interpreted Patterns

Table 1 lists the conditions discussed with the urologists that were considered in the choice of different uroflow patterns in the proposed approach. The voided volume (*VV*) and the maximum flow rate (*Qmax*), *i.e.* the highest peak flow rate, are standard parameters among all of the parameters generated by uroflowmetry tests [20]. *Qmax*, which is an important parameter in the evaluation of the adult voiding function, does not apply well in

Table 1. The conditions for different uroflow patterns.

Types	Normal	Abnormal				
Patterns	Bell	Tower	Staccato	Interrupted	Plateau	Obstructive
Conditions						
1. *Qmax*	≥ 15.0 ml/sec	≥ 25.0 ml/sec			< 15.0 ml/sec	< 15.0 ml/sec
2. Rising angle	≤ 85°	86° - 90°				
3. Drop of the flow rate			≥ 2 ml/sec			
4. Drop angle			≥ 70°			
5. Significant drops			≥ 3			
6. Flow rate reaching zero				Yes		
7. Small curve area				≥ 20%*VV*		
8. Voided volume		< 200 ml				
9. Flow index					< 0.66	≥ 0.66

children [9]. A maximum flow rate of less than 15 ml/sec is classified as abnormal. However, we cannot be sure that the condition with $Qmax \geq 15$ ml/sec is normal because there are some types of abnormal pattern with $Qmax \geq 15$ ml/sec. Therefore, we divided *Qmax* into three levels: (1) less than 15 ml/sec; (2) more than or equal to 15 ml/sec; and (3) more than or equal to 25 ml/sec.

In our study, we propose the rising angle as the interpretation condition, defined as

$$\text{Rising Angle} = \arctan(Qmax/TQmax)\times 180/\pi. \tag{1}$$

In Eq. (1), *TQmax* denotes the time to the maximum flow rate. We can obtain the rising angle, which is the interior angle, between the horizontal axis and the segment from the start of urine flow to the maximum flow rate, as shown in Fig. 2 (a). A rising angle with too high a value represents a flow rate that reaches its maximum over 25 ml/sec in a short time, which is a feature of the Tower-shaped pattern. A rising angle with too low a value represents a flow rate that takes a long time to reach its maximum value, and this phenomenon usually means that *Qmax* is not greater than the standard value (≥ 15 ml/sec).

The situation of several significant drops is an important condition defining the Staccato-shaped pattern. The flow rate of the Staccato-shaped pattern is the same as that of the Bell-shaped pattern. That is, their maximum flow rate must be greater than or equal to 15 ml/sec. We can use the significant drop to distinguish the Bell-shaped from the Staccato-shaped pattern because a urine flow rate dropping rapidly repeatedly many times is an abnormal phenomenon. At the beginning of the uroflowmetry test, the peak point *PP* is the point at which the increasing flow rate starts to decrease, while the bottom point *BP* is the point at which the decreasing flow rate starts increasing. It is possible that several drops may occur in many normal flow curves, but such a drop of the flow rate is less than 2 ml/sec; therefore, we do not regard this situation as a significant drop.

Fig. 2 (b) shows many parameters for the drop in the flow curve. Assume that each point *P* on the curve is defined as a pair (*P.T*, *P.Q*), where *P.T* is the current time of the

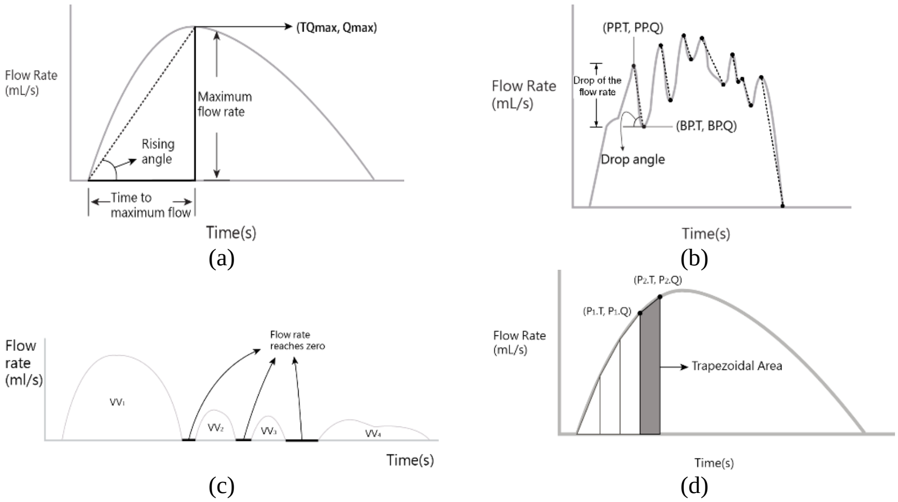

Fig. 2. Observation: (a) The rising angle in the flow curve; (b) The drop in the flow curve; (c) The flow rate of zero; (d) Computing the trapezoidal area.

flow rate at this point (in seconds) and $P.Q$ is the current urine flow rate. Point coordinates ($PP.T$, $PP.Q$) and ($BP.T$, $BP.Q$) represent the points of the peak and the bottom, respectively. The drop of the flow rate shown in Fig. 2 (b) is defined in Eq. (2).

$$\text{Drop of the Flow Rate} = PP.Q - BP.Q \tag{2}$$

The drop angle is the interior angle between the segment from point PP to point BP and the horizontal axis, as shown in Fig. 2 (b), and is formally defined in Eq. (3).

$$\text{Drop Angle} = |arctan(PP.Q - BP.Q)/(BP.T - PP.T)| \times 180/\pi. \tag{3}$$

Moreover, the cluster of drops means that the number of drops meets the criteria in the pattern. For example, in Fig. 2 (b), we observe the cluster of drops is equal to 7.

The flow rate reaching zero defines an interval between two curves, indicating that the bladder has suspended urination during the voiding time. Fig. 2 (c) shows that the urine flow rate reaches zero. The interpretation of the Interrupted-shaped pattern considers not only the flow rate reaching zero, but also the size of the area of the small curves. Therefore, it is based on the interval between the two curves.

All the areas under the curve in the pattern represent the voided volume. The voided volume VV, also called the urine volume, is defined in Eq. (4).

$$VV = VV_1 + VV_2 + VV_1 + \ldots + VV_n \tag{4}$$

In Eq. (4), VV_1 denotes the first area under the curve, and the others follow similarly. According to the conditions required for the Interrupted-shaped pattern, when the flow rate reaches zero, we need to add all of the areas under the small curve to check whether their total volume is greater than 20 percent of the voided volume. For example, there are four curves in the pattern, with VV_1 as the main curve while VV_2, VV_3 and VV_4 are small curves, as shown in Fig. 2 (c).

The voided volume is given by the uroflowmeter. However, we need to know the area of the small curves as our condition, so we use the two-dimensional coordinates to compute it. We compute the trapezoidal area between two coordinates as shown in Fig. 2 (d). The trapezoidal area formula is given in Eq. (5).

$$Trapezoidal\ Area = \frac{(P_1.Q+P_2.Q)\times|P_1.T-P_2.T|}{2}. \quad (5)$$

Then, the sum of all the trapezoidal areas TA_i ($1 \le i \le n$) covering the small curve is the area of the curve.

A quantitative approach to the interpretation of uroflowmetry has been proposed by Franco *et al.* [14]. We include the flow index in [14] as one of the conditions of interpretation to distinguish the Obstructive-shaped from the Plateau-shaped pattern.

2.2 The Grading Policy for Patterns

In this section, we present a grading approach that gives each condition a grade and computes the total grade by assigning different weights for different conditions before classifying each uroflow pattern. The pattern with the highest grade is the final diagnosed pattern.

2.2.1 Grades for different conditions

We know that the interpretation of the different uroflow patterns is easily overlapped by a single condition. Thus, we propose a grading method which gives each condition *c* a grade denoted by $Grade_c$, $0 \le Grade_c \le 1$, and a different weight denoted by $Weight_c$, $Weight_c \ge 1$, for each uroflow pattern. The grading method is given in Eq. (6).

$$Score = \frac{\sum Weight_c \times Grade_c}{\sum Weight_c}. \quad (6)$$

For example, the weight and grade of the Interrupted-shaped condition are assigned according to Table 2 (a). The Interrupted-shaped pattern has the flow rate reaching zero between the two curves, and the flow rate reaching zero is a necessary condition for a small curve. Therefore, the Interrupted scoring method first concerns whether the number of curves is larger than 0. If the condition is true, its score is the corresponding grade for the related condition of areas under small curves. According to Table 2 (a) and Eq. (6), the score of the Interrupted-shaped condition, *IScore*, is given in Eq. (7).

$$IScore = \frac{1 \times Grade_1}{1} \quad (7)$$

Note that in Table 2, the weight and grade of each condition were confirmed by Dr. Yang from his experience. In fact, it can be adjusted by different urologists based on their experiences.

The Staccato-shaped pattern is characterized by the significant drop and the cluster, and the grades for the different conditions for determining the Staccato-shaped pattern are presented in Table 2 (b). The scores of the Bell-shaped, the Tower-shaped, the Plateau-shaped, and the Obstructive-shaped patterns are decided according to the related grade and weight as shown in Tables 2 (c)-(f), respectively.

Table 2. The grading policy: (a) The interrupted-shaped; (b) The staccato-shaped; (c) The bell-shaped; (d) The tower-shaped; (e) The plateau-shaped; (f) The obstructive-shaped.

Interrupted-shaped pattern			
Conditions		Weight	Grade
1. Areas of small curves	≥ 20%*VV*	1	100%
	≥ 15%*VV*	1	80%
	≥ 10%*VV*	1	60%
	< 10%*VV*	1	0%

(a)

Staccato-shaped pattern			
Conditions		Weight	Grade
1. Cluster of significant drops	≥ 3	1	100%
	< 3	1	0%

(b)

Bell-shaped pattern			
Conditions		Weight	Grade
1. Qmax	$\geq 15.0 ml/s$	7	100%
	$\geq 14.0 ml/s$	7	99%-70%
	$< 14.0 ml/s$	7	0%
2. Rising angle	$\leq 85^o, > 60^o$	3	100%
	$\geq 45^o$	3	70%
	$< 45^o$	3	0%

(c)

Tower-shaped pattern			
Conditions		Weight	Grade
1. Qmax	$\geq 25.0 ml/s$	3	100%
	$> 24.5 ml/s$	3	99%-1%
	$\leq 24.5 ml/s$	3	0%
2. Rising angle	$\leq 90^o, > 85^o$	3	100%
	$\geq 80^o$	3	70%
	$< 80^o$	3	0%
3. Voided volume	$\geq 300 ml$	4	0%
	$\geq 250 ml$	4	60%
	$\geq 200 ml$	4	80%
	$< 200 ml$	4	100%

(d)

Plateau-shaped pattern			
Conditions		Weight	Grade
1. Qmax	$\geq 15.0 ml/s$	6	0%
	$< 15.0 ml/s$	6	100%
2. Flow index	≥ 0.66	4	0%
	< 0.66	4	100%

(e)

Obstructive-shaped pattern			
Conditions		Weight	Grade
1. Qmax	$\geq 15.0 ml/s$	6	0%
	$< 15.0 ml/s$	6	100%
2. Flow index	≥ 0.66	4	100%
	< 0.66	4	0%

(f)

2.2.2 The priority of interpretation of uroflowmetry curves

Since several patterns have some overlapping conditions, the computation of scores of the curve patterns follows the following sequence. First, the Interrupted-shaped pattern has the highest priority because its conditions contain the most direct consideration. Its conditions are that the flow rate has reached zero, and all areas under the small curves should be greater than 20% of the voided volume. When the curve satisfies these two conditions, we classify it as the Interrupted-shaped pattern, regardless of whether the maximum flow rate *Qmax* is high or low, or the curve is similar to the other patterns. Therefore, if the flow curve is the Interrupted-shaped pattern, *i.e.*, *IScore* > 0.5, the scores of the other five patterns will be decreased by multiplying by 0.8.

The Staccato-shaped pattern has the second highest priority. The maximum flow rate does not need to be confirmed because only the number of significant drops is important. Therefore, if the flow curve is the Staccato-shaped pattern, *i.e.*, its corresponding score *SScore* > 0.9, the scores of the other patterns, except the Interrupted-shaped pattern, will be decreased by multiplying by 0.8.

After we calculate the score for each pattern, the chosen pattern is the one with the highest score among those six patterns.

3. PERFORMANCE

3.1 Performance Model

This study was approved by Taipei Tzu Chi Hospital and was performed in accordance with the ethical standards in the Declaration of Helsinki. Written informed consent was obtained from all patients for the study. As stated in [4], the interpretation of uroflowmetry is usually subjective and empirical. It is highly dependent on the urologists' experience. Each urologist has a different way of explaining the interpretation of the flow curve so that the results of the uroflowmetry interpretation may be inconsistent among urologists. Therefore, in the following performance evaluation, to reduce bias from only one urologist's opinion, the results of the proposed approach were compared with the same results of Dr. Yang's and Dr. Chuang's observations on the classification of the uroflowmetry curves. The use of consensus between two experts to establish objective criteria and grading for uroflowmetry is new in urology. The original medical data of 160 cases were provided along with the primary diagnosis from uroflowmetry conducted at the Department of Urology, Tzu Chi Hospital, New Taipei. The same results identified by both two highly experienced urologists were 87 cases out of 160. The urologists evaluated the uroflowmetry curves independently after reviewing the definition of each uroflowmetry curve as recommended by the International Children's Continence Society (ICCS) [11].

The study in [4] indicated that published reports show high inter-observer discrepancy for the same uroflowmetry curves. In their work, the inter-observer agreement was analyzed using kappa statistics. Therefore, in this study, following the same evaluation model in [4], the agreement between the urologists' observation and the proposed approach was analyzed using statistics with Cohen's *kappa* coefficient as in Eq. (9), which is the grade of agreement for qualitative items.

$$\text{Cohen's } kappa \text{ coefficient} = \frac{(P_{observed} - P_{expected})}{(1 - P_{expected})}. \tag{9}$$

In Eq. (9), $P_{observed}$ is the relative observed agreement among raters, and $P_{expected}$ is the hypothetical probability of chance agreement, using the observed data to calculate the probabilities of each observer's selection of each category. The grade of agreement is classified as the Altman suggestion [21]. The different ranges of the *kappa* value have different interpretations. For the range between 0.61 and 0.8, the interpretation is good agreement. For the range between 0.81 and 1, the interpretation is very good agreement.

3.2 Experimental Results

We analyzed the results of automatic classification with the proposed approach and Dr. Yang's and Dr. Chuang's visual observations, as shown in Table 3. Table 3 shows the results of classification by (1) the proposed approach and (2) Dr. Yang's and Dr. Chuang's observation. Obviously, the definition of the Plateau-shaped and the Obstructive-shaped patterns differs between our approach and Dr. Yang's and Dr. Chuang's observation for many tests. Therefore, we used the statistical approach with Cohen's *kappa* coefficient to do the further analysis.

Table 3. Classification results comparison.

	Proposed approach	Dr. Yang's and Dr. Chuang's observation
Patterns	Quantity	Quantity
Bell	22	19
Tower	1	2
Staccato	10	9
Interrupted	8	3
Plateau	12	1
Obstructive	34	53
Total	87	87

Table 4. The agreement between the proposed approach and Dr. Yang's and Dr. Chuang's observations: the normal type vs. the abnormal type

Dr. Yang and Dr. Chuang	Proposed approach		
	Normal	Normal	
Normal	<u>18</u>	1	(19)
Abnormal	4	<u>64</u>	(68)
	(22)	(65)	87
Cohen's *Kappa* Coefficient = 0.84			Very Good agreement

Table 4 shows that the results of the proposed approach and Dr. Yang's and Dr. Chuang's observations agree that 18 uroflowmetry curves are of the normal type and 64 flow curves are abnormal. On the other hand, the definitions of only (1 + 4) flow curves disagreed. The proposed approach and the observations by both urologists have very good agreement (*kappa* = 0.84) when interpreting normal and abnormal uroflowmetry curves.

If we do not consider the low *Qmax* (*i.e.*, without considering the distinction of the Plateau-shaped and the Obstructive-shaped patterns), the agreement in classifying specific patterns of uroflowmetry curves is good as shown in Table 5 (*kappa* = 0.71).

For the agreement of abnormal types, we use the Tower-shaped pattern as the test case. Note that of the conditions to decide the abnormal type of uroflowmetry curves, only *Qmax* can be seen directly. Moreover, *VV* is given in the report. The agreement in classifying the Tower-shaped pattern and the Non-Tower-shaped pattern of uroflowmetry curves is good, as shown in Table 6 (*kappa* = 0.66). With the proposed approach, we can compute the rising angle, but the urologists found it difficult to accurately measure the rising angle by visual observation.

To evaluate automatic classification of new medical data, 46 new cases apart from the original 160 cases were analyzed. Table 7 shows the test results of 46 new cases when interpreting normal and abnormal uroflowmetry curves. The proposed approach and the observations by both urologists have very good agreement (*kappa* = 0.82).

3.3 Discussions

The summary of conditions for uroflow patterns in this study is listed in Table 8. This can provide a guideline for the heuristic settings discussed with the experienced urologists to set the parameters in further investigation. After making so many comparisons between our approach and the observation from two highly experienced urologists, we have the following suggestions for urologists to take care of voiding dysfunctions.

Table 5. The agreement between the proposed approach and Dr. Yang's and Dr. Chuang's observations: specific patterns without the plateau-shaped and the obstructive-shaped patterns.

Dr. Yang and Dr. Chuang	Proposed approach Bell	Tower	Staccato	Interrupted	Low Qmax	
Bell	<u>18</u>	0	0	0	1	(19)
Tower	1	<u>1</u>	0	0	0	(2)
Staccato	2	0	<u>6</u>	1	0	(9)
Interrupted	1	0	0	<u>2</u>	0	(3)
Low Qmax	0	0	4	5	<u>45</u>	(54)
	(22)	(1)	(10)	(8)	(46)	87
Cohen's *Kappa* Coefficient = 0.71					Good agreement	

Table 6. The agreement between the proposed approach and Dr. Yang's and Dr. Chuang's observations: Tower-shaped vs. Non-Tower-shaped.

Dr. Yang and Dr. Chuang	Proposed approach Tower	Non-tower	
Tower	<u>1</u>	1	(2)
Non-tower	0	<u>85</u>	(85)
	(1)	(86)	87
Cohen's *Kappa* Coefficient = 0.66			Good agreement

Table 7. The agreement between the proposed approach and Dr. Yang's and Dr. Chuang's observations: new cases.

Dr. Yang and Dr. Chuang	Proposed approach Normal	Normal	
Normal	<u>16</u>	0	(16)
Abnormal	4	<u>26</u>	(30)
	(20)	(26)	46
Cohen's *Kappa* Coefficient = 0.82			Very Good agreement

Table 8. The summary of the conditions for uroflow patterns.

Pattern	Conditions
Bell	1. *Qmax* ≥ 15 ml/sec 2. Rising angle between 45° and 85°
Tower	1. *Qmax* ≥ 25 ml/sec 2. Rising angle between 86° and 90° 3. *VV* < 200 ml
Staccato	1. Significant drops ≥ 3
Interrupted	1. Small curve area ≥ 20%*VV*
Plateau	1. *Qmax* < 15 ml/sec 2. Flow index < 0.66
Obstructive	1. *Qmax* < 15 ml/sec 2. Flow index ≥ 0.66

First, the interpretation of the Plateau-shaped or the Obstructive-shaped patterns could be distinguishable based on the value of the flow index. Moreover, the value 0.66 is computed by the formula suggested by Franco *et al.* [14], and it may be still discussible under many special cases. Therefore, the urologist may regard the Plateau-shaped pattern and the Obstructive-shaped pattern together as the same pattern without the consideration of the flow index. The recognition of plateau and obstructive patterns is quite different between the proposed approach and two urologists' observations. The conditions for recognizing plateau and obstructive patterns can be further investigated to improve performance.

Second, for the interpretation of the Bell-shaped pattern or the Tower-shaped pattern, the related Condition 1 of the Bell-shaped pattern (with the condition $Qmax \geq$ 15ml/sec) could be covered by Condition 1 of the Tower-shaped pattern (with the condition $Qmax \geq$ 25ml/sec). Basically, the unit of the *x*-axis should be same as the unit of the *y*-axis. If this factor is concerned carefully, the urologist could be easy to see the rising angle to distinguish those two patterns (the rising angle ≤ 85 degree for the Bell-shaped pattern and the rising angle > 85 degree for the Tower-shaped pattern).

Third, for the interpretation of the Staccato-shaped pattern, the urologist may consider the drop flow rate and the drop angle.

Forth, for the interpretation of the Interrupted-shaped pattern, the urologist could check whether the flow curve reaches zero or not before the end of the test and considers the area of the small curve. The interval is given by the uroflowmeter. The number of intervals indicates the number of the case of the flow rate reaching zero. When the number of intervals is greater than one, it implies that the case of the flow rate reaching zero has occurred, not only at the end of the test. Therefore, even though the urologist could not see the case of the flow rate reaching zero clearly, the urologist could confirm that such a case has occurred at least once from the number of intervals. For the part concerning the total area of the small curves, it could be computed by observing the amount of the increment of the voided volume during the time that the small curve occurs, since both graphs (the flow curve and the volume curve) reported from the test have the same *x*-axis (*i.e.*, time) and are shown at the same time vertically.

Finally, in fact, the main concern is whether the flow curve is normal or abnormal. Therefore, if the urologist could concern the three factors carefully, including (a) the adjustment of the unit of the *x*-axis and the unit of the *y*-axis to be one to one; (b) regarding *Qmax* as the key point for the decision; and (c) checking the number of intervals, we think that the urologist's subjective observation could be similar to the objective result from our approach.

4. CONCLUSION

In this paper, we have proposed an automatic approach to classifying uroflowmetry curves, efficiently interpreting the uroflowmetry in real time. In our approach, we define a rising angle and use the flow rate of the drop as conditions to help us evaluate the uroflowmetry curves. We combined several conditions for the classification of uroflowmetry curves, which use weighting to evaluate the importance of different patterns. This enhanced the agreement of the classification of the uroflowmetry curves with the urologist's diagnosis. In fact, the values of the grade and the weighting are adjustable based on the urologist's experience, and the values of those conditions (including the raising angle, the drop angle and the number of drops) can also be discussed. In our performance study, we examined the agreement between the same answer of two urologists' observations and our proposed approach to the classification of uroflowmetry curves. Experimental results have shown that the proposed approach has very good agreement with the urologists' observations. Identifying uroflow patterns is usually subjective and empirical, and each urologist has a different way of explaining the uroflowmetry interpretation. In this study, the results of the proposed approach were compared with two highly experienced urologists' observation. In the future, more experts will be invited to validate the use of such objective criteria and grading.

ACKNOWLEDGMENT

This research was supported in part by the Division of Urology, Taipei Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, New Taipei, Taiwan. Our gratitude also goes to Alison M. Fisher, professional English editor, for her assistance with proofreading.

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