·Investigation·

Profitability analysis of a femtosecond laser system for cataract surgery using a fuzzy logic approach

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Abstract

• **AIM: To define the financial and management conditions required to introduce a femtosecond laser system for cataract surgery in a clinic using a fuzzy logic approach.**

• **METHODS: In the simulation performed in the current study, the costs associated to the acquisition and use of a commercially available femtosecond laser platform for cataract surgery (VICTUS, TECHNOLAS Perfect Vision GmbH, Bausch & Lomb, Munich, Germany) during a period of 5y were considered. A sensitivity analysis was performed considering such costs and the countable amortization of the system during this 5y period. Furthermore, a fuzzy logic analysis was used to obtain an estimation of the money income associated to each femtosecond laser-assisted cataract surgery (G).**

• **RESULTS: According to the sensitivity analysis, the femtosecond laser system under evaluation can be profitable if 1400 cataract surgeries are performed per year and if each surgery can be invoiced more than $500. In contrast, the fuzzy logic analysis confirmed that the patient had to pay more per surgery, between $661.8 and $667.4 per surgery, without considering the cost of the intraocular lens (IOL).**

• **CONCLUSION: A profitability of femtosecond laser systems for cataract surgery can be obtained after a detailed financial analysis, especially in those centers with large volumes of patients. The cost of the surgery for patients should be adapted to the real flow of patients with the ability of paying a reasonable range of cost.**

• **KEYWORDS:** cataract surgery; femtosecond laser; fuzzy logic; femto-cataract; victus; profitability analysis

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INTRODUCTION

The introduction of the femtosecond laser technology in cataract surgery to facilitate and optimize the surgical procedure has supposed a great step forward [1]. Specifically, systems based on this laser technology perform automatically some steps of the surgery, such as the capsulorrhexis, the lens segmentation, and corneal incisions [2]. This allows a superior surgical performance compared to conventional phacoemulsification in terms of effective phaco time [3-6] and preservation of corneal endothelium and IOL centration [7]. This is a good addition to cataract surgery despite it adds few remarkable advantages to experienced phacoemulsification surgeons [8]. However, there is some controversy concerning the cost-effectiveness of this technology and about how to make it profitable in clinical practice [9]. The aim of this study was to define the financial and management conditions required to introduce and make profitable a femtosecond laser system for cataract surgery in a clinic using a fuzzy logic approach.

SUBJECTS AND METHODS

Sensitivity Analysis In the simulation performed in the current study, the costs associated to the acquisition and use of a commercially available femtosecond laser platform for cataract surgery during a period of 5y were considered. Specifically, the costs corresponding to the acquisition and use of the Victus femtosecond laser platform from Technolas Perfect Vision GmbH (Bausch & Lomb, Munich, Germany) were analyzed. Assuming a progressive payment of this laser system in 5y, Table 1 summarizes the distribution of costs associated to the acquisition of this laser platform.

A sensitivity analysis was performed considering the total costs of the platform according to Table 1. For such analysis, a 5y period was considered whether it is a reasonable operating life for this machine. It should be remarked that this simulation may change significantly for other different periods of evaluation. Considering this period, the countable amortization of the femtosecond-based system was calculated which is the distribution of the costs during the operating life of the machine.

Table 1 Summary of the costs associated to the acquisition of the VICTUS system (Bausch & Lomb), assuming a progressive payment in 5y

Payment	Year 1	Year 2	Year 3	Year 4	Year 5	Total USD
Down payment	595 000	130 000	130 000	130 000	130 000	1 115 000
Quarterly instalments	49 583	49 583	49 583	-	-	595 000
Monthly instalments	17 250	21 563	25 875	31 238	37 719	1 603 733
Total per year	1 000 333	587 083	638 833	504 850	582 633	3 313 733

-: No payment.

With this sensitivity analysis, the following variables were estimated: cost per patient, structural cost, and indirect costs associated to the activity performed with the femtosecond machine. We considered the costs that are directly related to the surgery and to the use of disposable materials. Finally, the total cost per surgery was estimated.

Application of Fuzzy Logic to Estimate the Potential Income Flow The number of patients that can attend to our clinic requiring and/or needing for femtosecond laser-based cataract surgery is something that cannot be known with certainty. Likewise, it is uncertain the quantity of money that patients are ready to pay for this new modality of cataract surgery. However, this information has a significant influence on any type of estimation about the financial requirements for the use of femtosecond laser-based devices. There are even intangible costs that cannot be quantified with accuracy. Therefore, the estimation of the potential income flow due to femtosecond laser-based cataract surgeries is uncertain and very subjective as the evolution of the flow of patients cannot be known with certainty as well as how technological changes will affect to the obsolescence of femtosecond machines. For this reason, we applied the theory of fuzzy subsets to our simulation that allow improving the quantification processes of elements that cannot be quantified easily [10-13]. In ophthalmology, fuzzy logic has been used to classify eye diseases [14], to analyze and classify retinal or optical coherence tomography images [15-16], analysis of ocular movements [17], and to identify retinal exudates in diabetic retinopathy [18]. In our study, as previous authors have done, we used the fuzzy logic principles to define a methodology of quantification of the intangible assets. This analysis provides more certainty to the evaluation of the income flow due to femtosecond-based cataract surgery in an ophthalmological clinic and allows us to define a strategy for making profitable the use of this machine. Specifically, in our study, we developed a sequential process subdivided in seven stages:

1) Selection of the target variable or variables. Specifically, in our analysis the money income associated to each femtosecond laser-assisted cataract surgery (G) was the target variable;

2) Evaluation of G by some experts. We asked to a group of experts for an evaluation of G considering their knowledge, experience and the information of this economic sector. As their opinions were approximations, they were transformed into confidence triplets;

3) First approximation of the intangible value of G. The arithmetic mean was calculated assuming the same level of confidence for all experts. The result was a fuzzy number informing about the approximated achievable values for the analyzed variable;

4) Application of the expertise method. It consists on summarizing the opinions expressed by some experts in an interval and yielding it to a new expert evaluation. Thus, the opinions are focused further, with a reduction of the amplitude of the interval and, therefore, of the uncertainty and subjectivity. The results of this re-evaluation will be an experton that will reflect the opinions of the new experts. Specifically, five new experts performed a new evaluation using the following semantic correspondence: 0=575.00 is correct; 0.1=practically 575.00; 0.2=almost 575.00; 0.3= close to 575.00; 0.4=closer to 575.00 rather than to 715.00; 0.5=as close to 575.00 as to 715.00; 0.6=closer to 715.00 rather than to 575.00; 0.7=close to 715.00; 0.8=almost 715.00; 0.9=practically 715.00; and 1.0=715.00 is correct. The utilization of this methodology facilitates to the expert the representation of the experts' thoughts, improving thus the sensitivity of the analysis.

Once recorded the opinions of the five experts, the experton was built. For such purpose, the absolute frequencies, relative frequencies and inverse accumulated frequencies were determined. As the opinions of the experts were expressed in confidence triplets, the number of times that each value appears in the inferior (Li) and superior (Ls) extremes of the interval, as well as in the center of it (Vc), were determined for the estimation of absolute frequencies.

5) Calculation of the R^+-Experton. Once determined the M-Experton, the following step was to perform its transformation into aR^+-Experton, which allowed the expression of the opinions of the experts in financial terms.

6) Calculation of the expected value of G. The mathematical expectation of the R^+-Expertons were obtained and therefore an expected mean value of the analyzed variable represented by a fuzzy number was obtained;

7) Calculation of the final value of G.

RESULTS

Modelling and Sensitivity Analysis Table 1 summarizes the results of the sensitivity analysis. With the data used, the mean cost per surgery was estimated to be $524.71.

Assuming that the patient paid \$500, the analytical result of our analysis was \$-24.71. In other words, this equipment can be profitable if 1400 cataract surgeries are performed per year and if each surgery can be invoiced more than \$500. This analysis will allow different tests of sensitivity considering the different situations that may happen in clinical practice.

Fuzzy Logic Analysis Six independent experts on cataract surgery (not commercially-biased) were consulted and provided an evaluation of G, the potential money income associated to each femtosecond laser-assisted cataract surgery in an ophthalmological clinic. Table 2 shows a summary of the results of this consult. The expert number 1 considered that G was within the interval (600.00, 650.00), whereas the opinion of the expert number 4 was expressed by means of a fuzzy triangular number, considering that in normal conditions the income was \$600.00 (presumption level 1), but it reached values between (500.00, 700.00; presumption level 0) when the uncertainty increased.

Assuming the same level of confidence for all experts, the arithmetic mean of G was calculated as follows:

M (G) =1/6×{[600.00, (600.00, 650.00), 650.00] + [550.00, (550.00, 750.00), 750.00] + [550.00, (550.00, 700.00), 700.00] + [500.00, (600.00, 600.00), 700.00] + [600.00, (600.00, 740.00), 740.00] + [650.00, (700.00, 700.00), 750.00]} = [575.00, (600.00, 690.00), 715.00].

The result was a trapezoid fuzzy number that estimated that the variable G will range under conditions of maximum uncertainty in the interval (575.00, 715.00), with the maximum level of probability for the interval (600.00, 690.00).

Table 3 summarizes the results of the re-evaluation performed by five independent experts of the outcomes obtained in the first evaluation. The expert number 1 considered that the intangible variable G was close to \$715.00, whereas the expert number 3 estimated that G ranged between quantities close to \$715.00 and practically 715.00 (0.7= close to 715.00; 0.8= almost 715.00; 0.9= practically 715.00). Table 4 shows the experton obtained after the analysis of the re-evaluation performed by five independent experts. As shown, the column of absolute frequencies shows that 0.6 appeared two times as a central value of the interval, one time as a superior extreme and another time as an inferior extreme, whereas 0.9 appeared only one time as superior extreme of the interval. The column of relative frequencies shows the absolute frequencies divided by the number of experts. Finally, the column of inverse accumulated frequencies was calculated by accumulating frequencies from the level 1 (from bottom to top). As the opinions from experts in our study were expressed as confidence triplets, an M-Experton was obtained, where Li is the inferior limit, Vc is the central value and Ls is the superior limit of the interval.

Table 2 Results of the consultation of six independent experts on cataract surgery (not commercially-biased) that provided an evaluation of G

Expert	Evaluation of G	Confidence triplets of G
1	600.00, 650.00	[600.00, (600.00, 650.00), 650.00]
2	550.00, 750.00	[550.00, (550.00, 750.00), 750.00]
3	550.00, 700.00	[550.00, (550.00, 700.00), 700.00]
4	500.00, 600.00, 700.00	[500.00, (600.00, 600.00), 700.00]
5	600.00, 740.00	[600.00, (600.00, 740.00), 740.00]
6	650.00, 700.00, 750.00	[650.00, (700.00, 700.00), 750.00]

Table 3 Results of the re-evaluation by five independent experts of the first evaluation of G

Expert	Evaluation
1	0.7
2	0.6
3	0.7, 0.8, 0.9
4	0.5
5	0.5, 0.6, 0.7

Table 4 Representation of the experton *n*= Li/Vc/Ls

Pressumption level	Absolute frequencies	Relative frequencies	Inverse accumulated frequencies
0	0/0/0	0/0/0	1/1/1
0.1	0/0/0	0/0/0	1/1/1
0.2	0/0/0	0/0/0	1/1/1
0.3	0/0/0	0/0/0	1/1/1
0.4	0/0/0	0/0/0	1/1/1
0.5	2/1/1	0.4/0.2/0.2	1/1/1
0.6	1/2/1	0.2/0.4/0.2	0.6/0.8/0.8
0.7	2/1/2	0.4/0.2/0.4	0.4/0.4/0.6
0.8	0/1/0	0/0.2/0	0/0.2/0.2
0.9	0/0/1	0/0/0.2	0/0/0.2
1	0/0/0	0/0/0	0/0/0

The linear transformation of an experton, whose data are defined in an interval (0, 1), into a R^+-Experton, referenced as an interval $[A_1, A^2]$ where A_1 represents the inferior limit of the interval and A^2 the superior limit, was performed as follows:

R^+- Experton=A_1+(A^2-A_1)×Experton

In our study, this transformation was as follows (Table 5):

R^+-M-Experton=575.00+(715.00-575.00)×M-Experton

After this, a mean value of G was obtained as follows:

E (A)=1/10 ×[(715.00, 715.00, 715.00)+ (715.00, 715.00, 715.00)+(715.00, 715.00, 715.00) + (715.00, 715.00, 715.00) + (715.00, 715.00, 715.00)+ (659.00, 687.00, 687.00)+(631.00, 631.00, 659.00)+(575.00, 603.00, 603.00)+(575.00, 575.00, 603.00)+(575.00, 575.00, 575.00)]=(659.00, 664.60, 670.20).

The final result was a triangular fuzzy number that represents the intangible income (G) that can be compared with the financial register of a specific clinic. Figure 1 shows a graphic display of the mean triangular fuzzy number obtained. This number expresses that the value of G was in the interval (659.00, 670.20), with the most probable value

Table 5 Representation of the R^+-M-Experton

Pressumptionlevel	R^+-M-Experton (Li/Vc/Ls)
0	715.00/715.00/715.00
0.1	715.00/715.00/715.00
0.2	715.00/715.00/715.00
0.3	715.00/715.00/715.00
0.4	715.00/715.00/715.00
0.5	715.00/715.00/715.00
0.6	659.00/687.00/687.00
0.7	631.00/631.00/659.00
0.8	575.00/603.00/603.00
0.9	575.00/575.00/603.00
1	575.00/575.00/575.00

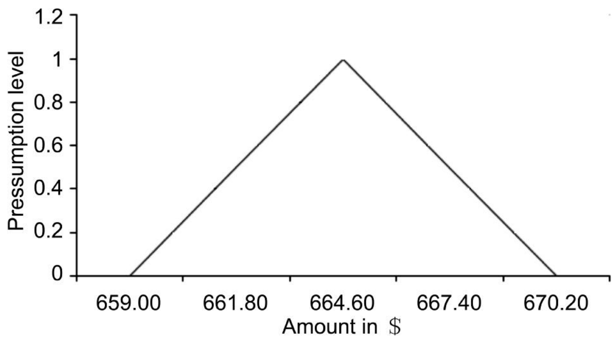

Figure 1 Fuzzy number representing G, the potential money income associated to each femtosecond laser-based cataract surgery in an ophthalmological clinic.

according to the experts of $664.60.

Finally, the process of fuzzy logic concluded with the calculation of the mathematical expectation associated to the mean fuzzy number obtained (Figure 1). Thus, the fuzzy number is transformed into a confidence interval, eliminating the subjectivity and therefore introducing objectivity in the estimation of the intangible evaluated.

Being A ($\propto$) a fuzzy number represented as a confidence interval where the level of presumption $\propto$ varies within the interval (0, 1), its mathematical expectation was obtained by performing the following calculation:

$$E[A(\propto)]=\int_0^1 A(\propto)d\propto$$

As the fuzzy number was triangular in our study, its characteristic function waslinear, and its representation by means of confidenceintervals was as follows:

$A(\propto) = [(664.60\text{-}659.00)\times(\propto+659.00,\ (664.60\text{-}670.20)\times(\propto+670.20]$

Finally, the mathematical expectation was calculated as follows:

$$E[A(\propto)]=\int_0^1 [560\propto+659.00,\ 670.20\text{-}560\propto]\,d\propto$$

$$E[A(\propto)]=[661.80,\ 667.40]$$

In summary, the fuzzy number was transformed into a confidence interval ranging between $661.80 and $667.40. If our sensitivity analysis revealed previously that a patient should pay $500 per femtosecond laser-assisted surgery, this fuzzy logic analysis confirms that the patient should pay more per surgery, between $661.8 and $667.4 per surgery, without considering the cost of the IOL.

DISCUSSION

Cataract surgery is one of the most beneficial procedures for a patient's quality of life as it allows a visual restoration when significant visual disturbances are present and provides a compensation for presbyopia when multifocal IOLs are implanted. Likewise, cataract surgery is one of the most common surgical procedures performed and can become financially very efficient in many centers providing cataract care[19]. However, the introduction of femtosecond laser-based systems for cataract surgery in ophthalmological clinics and hospitals has been considered a new challenge, as it is currently a relatively expensive technology[9]. For this reason, studies evaluating from a management and financial perspective how to implement and make profitable this new technology in clinical setting should be performed. Corcoran[20] stated in a recent study that there are high barriers to entry into the marketplace for refractive surgery and refractive cataract surgery due to the high capital cost of excimer and femtosecond lasers, the high skill level required to deliver spectacular results to demanding patients who pay out of pocket, and the necessity to perform a high volume of surgeries to satisfy both of these requirements. In the current study, we have simulated for a specific femtosecond laser platform for cataract surgery that is currently available in the market which are the conditions necessary to obtain a financial benefit with this technique after estimating the potential cash flow achievable with this surgical procedure using fuzzy logic.

In a first sensitivity analysis, we have obtained that the femtosecond laser system evaluated can be profitable assuming a flow of 1400 cataract surgeries per year and a money income per surgery of more than $500, without considering the cost of the IOL. This flow of patients may be possible in clinics or hospitals with a great volume of patients, assuming that this payment per surgery can be assumed by all patients. However, this cost may seem excessive in many countries considering the conditions of the current world economic crisis. Another question is if this cost per surgery is justified considering the benefits of the surgery, but this was not the aim of our study. Abell and Vote [9] performed recently a comparative cost-effectiveness analysis of femtosecond laser-assisted cataract surgery and conventional phacoemulsification surgery. These authors concluded that laser cataract surgery, irrespective of potential improvements in visual acuity outcomes and complication rates, was not cost effective at its current cost to patient when compared with cost-effectiveness of phacoemulsification surgery [9]. They suggested that a significant reduction in the cost to patient (*via* reduced consumable/click cost) would increase the likelihood of femtosecond laser cataract surgery being considered cost effective [9]. Future studies must be performed to confirm the outcomes of this first cost-effectiveness analysis, but considering potential future changes in the cost of these systems and considering the results of future researches demonstrating additional advantages of femtosecond laser over conventional phacoemulsification surgery.

The second part of our study was the estimation by means of fuzzy logic the potential cash flow due to patients requiring or demanding femtosecond laser cataract surgery. Considering the opinions of different experts working in health centers with variable flow of patients, the analysis revealed that the patient should pay still more per surgery than in our previous estimation to make profitable the acquisition of this technology. Specifically, the money income per surgery should be between $661.8 and $667.4, without considering the cost of the IOL. This suggests that the acquisition and introduction of a femtosecond laser system for cataract surgery in any ophthalmological center should be done on the basis of a detailed and comprehensive financial analysis as the selection of an inappropriate cost for the surgery can lead to the unsustainability of the equipment. It should be considered that a high price for the surgery may ensure the profitability of the technology from a numerical point of view, but it can suppose a significant decrease in the flow of patients demanding the surgery and therefore can lead to a complicated financial situation. There are many advantages of femtosecond laser cataract surgery in terms of capsulotomy, fragmentation of the crystalline lens, corneal wound creation, and refractive results [1-7] that have been reported in several scientific studies, but these benefits should be also profitable in clinical practice.

In conclusion, femtosecond laser cataract surgery can be easily profitable in clinical practice of ophthalmological centers with large volumes of patients requiring or demanding cataract surgery. The cost of the surgery for patients should be adapted to the real flow of patients with the ability of paying a reasonable range of cost. The introduction of this type of surgery in more ophthalmological centers will depend on a potential lowering of the costs of this technology. Finally, the correct estimation of potential cash flows is essential for decision making in clinical practice. The use of fuzzy logic can be very useful in these situations, allowing a more adequate estimation of uncertain variables and allowing managers and surgeons to take more consistent decision. The collaboration between different areas of knowledge (economy, ophthalmology) in this type of decisions is crucial, as it cannot be only based on technical issues.

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