The learning curve in Foraminal Endoscopic Discectomy: experience needed to achieve a 90% success rate.

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Study Design. This study of 144 operated patients using endoscopic lumbar discectomy by transforaminal approach (YESS system) details one orthopedic surgeon's learning curve who has open spine surgery, knee and shoulder arthroscopic experience, but no previous endoscopic spine surgery experience.
Objective. To determine the learning curve and the number of cases needed to achieve a success rate of 90% similar to traditional transcanal surgery.
Summary of Background Data. To our knowledge there are no other studies determining the learning curve of the endoscopic lumbar discectomy by transforaminal approach.
Method. Transforaminal endoscopic discectomies as described by Yeung were done using the YESS system. Results were evaluated by modified MacNab criteria, and a questionnaire was used to determine the patient's satisfaction with the surgery. The average follow-up was 24.24 months. An algorithm analyzing the patient outcome, and the surgical time evolution were used in order to analyze at which case a success rate of 90% of good/excellent results was reached.
Results The mentioned parameters helped to place the cut for the calculated learning curve at case number 72. The results in the first 72 cases, were: 75 % good/excellent, 18.05 % fair, and 6.95 % poor, and in the following 72 cases: 90.28 % good/excellent, 9.72 % fair, and 0 % poor.
Conclusion. A learning curve of 72 cases was needed to reach the goal of 90% of good/excellent results.
Keywords*: transforaminal endoscopic discectomy, learning curve, posterolateral approach, surgical time*
Key points*:*

- *First study of the learning curve of endoscopic lumbar discectomy using the transforaminal approach*
- *Description of technical difficulties that must be surpassed in order to master the technique for an experienced surgeon*
- *Objective method to approximate the learning curve and quantify it.*

Introduction

Endoscopic transforaminal decompression techniques for radiculopathy secondary to lumbar disc herniation are recognized as an alternative surgical procedure to the microscope assisted transcanal approach[1-4]. The approach is foreign to most spine surgeons without specific training in their fellowships. Its high learning curve however, has discouraged surgeons from adopting the endoscopic technique as a first line consideration in treating herniated nucleus pulpous. This study attempts to provide information on the learning curve projected for a surgeon to achieve the technical ability to extract contained and extruded herniated disc fragments using a minimally invasive foraminal portal[1-4].

The first posterolateral percutaneous central nuclectomy was reported by Hijikata et al.[5] in 1975, followed by Kambin and Gellman's[6] report of nine cases in 1983. In 1983 Forst and Hausmann[7] reported the direct visualization of intervertebral disc space with a modified arthroscope. Schreiber et al.[8] used a biportal endoscopic technique. The transforaminal approach was reported by Mathews[9] in 1996, but this approach is the same portal utilized by Kambin[6] and Yeung[3]. Yeung[1-3] and Knight[10] used Holmium-YAG laser for foraminoplasty and decompression. In 1997 Yeung[1-3] introduced a rigid rod-lens, flow integrated, and multichannel operating spinal endoscope with slotted and bevel-ended cannulas that allowed for same-field viewing of the epidural space, annular wall, and intradiscal space.

Materials and Methods

Since January 2001 the senior author (RM) performed posterolateral endoscopic excisions of lumbar disc herniation, L1-L2 to L5-S1, on 144 consecutive patients using the YESS technique[1-3].
The general inclusion criteria for this study required clinical evidence of lumbar disc herniation by MRI and physical examination and more than 3 months of failed conservative treatment for intractable leg or buttock pain, with or without back pain.
Lumbar saggital and frontal X-rays, and MRI were the standard minimal images utilized to correlate symptoms of back and neuropathic pain. All 144 patients underwent provocation discography peri-operatively to confirm the reproduction of concordant pain. To be considered positive, the discogram pattern had to be abnormal (positive discography level = contrast escapes or profiles herniation). Discographic exclusion criteria were normal disc shape and non-reproduction of concordant pain. The transforaminal endoscopic procedure was performed only at positive levels as determined by concordant pain reproduction and an abnormal discogram pattern.

The procedure was performed as described by Yeung[1-3] using a 20° rigid endoscope with a working channel of 2.8 mm. (YESS™ system, Richard Wolf GmbH, Knittlingen, Germany); Laser Holmium-YAG 80 Watt with 90° side firing electrodes (Trimedyne Inc., Irvine, CA, USA); radiofrequency coagulation system (Ellman International Inc., Hewlett, NY, USA) and indigo carmine (Taylor Pharmaceuticals, Decatur, IL, USA) diluted with Iso-Vue 300 1:10 to blue stain abnormal nucleus pulpous and annular fissures.

Every procedure was video-recorded (mini-DV) for subsequent analysis and feedback learning purposes. Discography images were printed and added to the patient's documentation.

The results were classified using the modified MacNab criteria as seen in Table 1.

Result	Criteria
Excellent	An asymptomatic patient, medication not required
Good	Patient recovers fully from his sciatica symptoms but requires occasional use of medication for residual or recurrent pain.
Fair	Patient recovers partially and requires medication on a regular basis
Poor	Patient does not improve recover or recovers only partially, requiring medication on a regular basis. Patient not satisfied with the surgical results.

Table 1: Definition of the MacNab criteria for the results

Statistics

A relational database and client software was specifically designed to allow storage of the patient's personal data and the case's documentation. The software calculates follow-up median and standard deviation, age median and standard deviation, sex and result distribution of the operations.
The follow-up data of each patient was obtained by calculating the difference in days between the date of the operation and the ending date of this study. Then overall median and standard deviation of the follow-up data were computed. Conversion to months was done by dividing by 30 days.

The operated disc levels and the type of herniations can be seen in Table 2.

Disc level	L1- L2	L2- L3	L3- L4	L4- L5	L5- S1	Total discs
Number of discs	3	7	25	92	77	204
Percentage %	1.47	3.43	12.25	45.1	37.75	100
Herniation location	**bulging**	**central**	**lateral**	**foraminal**	**extra-foraminal**	**Total herniatons**
Number of herniations	60	26	46	71	1	204
Percentage %	29.41	12.75	22.55	34.8	0.49	100

Table 2: Disc levels and type of herniations

There were 96 (66.6%) male patients and 48 (33.4%) female patients.
The average male patient's age was 45.91 years and the average female patient's age was 44.56. The age range was 18 to 76 years. Global age average = 45.46 years, standard deviation = 12.42 years
The senior author (RM) is an orthopedic surgeon with 7 years of experience in spine surgery (open discectomies and percutaneous nuclectomies), as well as 12 years of experience in knee and shoulder arthroscopic surgery. He had not performed previous endoscopic spine surgery procedures.

The aim of this study is to determine the learning curve for the endoscopic surgical procedure on lumbar disc herniations based on measurable objective criteria[11] until reaching a target success result rate of 90% of good/excellent results by modified MacNab criteria.

Parameters

The first parameter for the determination of the learning curve was the evaluation of the success of the surgical procedure based on the patient's clinical record and a questionnaire comprising 4 questions (only yes/no answer), as described by Yeung et al.[1,2]. It was submitted to the patient after a min. of 6 months after the surgical procedure.

Questionnaire:

- *Since your endoscopic spine surgery, have you had subsequent lumbar spine surgery at the same level?*
- *Are you satisfied with the outcome of your endoscopic operation?*
- *Would you select the same endoscopic spine surgery again in the future, given the same disc herniation and your personal familiarity with the operative experience?*
- *Are your current back or leg symptoms, if any, worse than before your endoscopic back surgery?*

If one question was answered differently to the answer pattern No/Yes/Yes/No, the author considered that the surgical procedure failed.

The second parameter for the determination of the learning curve was the analysis of the evolution of the surgical time until its stabilization[11].

Surgical time was measured as the elapsed time between the first needle skin puncture and the final skin suture. Pre-operational instrument preparation and anaesthesia procedures are excluded from this time measurement.

Learning curve

As described in [11], a learning curve must contain a starting point (normally the 1st case), a learning rate (with increasing performance on patient outcome) and an asymptote when the expert level (control rate at 90%) is reached.

An algorithm was designed by the authors to analyze the patient outcome and to determine the case number for which the control rate of 90% of successful results was reached, as the rate accepted as equivalent to the inventor's technique in the literature is 91.2%[1,2].

Description of the implemented algorithm:

$$Y = 100 \times \frac{[N - M(N)]}{N} \qquad (1)$$

Y = successful results in % for N cases
N = number of cases (here: value goes from 1 to 144)
$M(N)$ = total sum of fair and poor cases within the N cases

N, as seen in equation 1, can be interpreted as a cutting point within the total number of cases *T=144*.
The algorithm runs iteratively for *N=1,2,3…T*, calculating for each N the success rate Y_{Res}, see equation 2, of all the cases following the cutting point N, while ignoring the cases previous to N and N itself.

$$Y_{Res}(N) = 1 - \frac{M_{Res}}{N_{Res}} \qquad (2)$$

M_{Res} = sum of fair and poor cases after N

N_{Res} = sum of all cases after N (see arrow)

Y_{Res} = success rate in $1/100$

Results

Patient outcome

The obtained curve for the patient outcome (ordinate Y_{Res}, abscissa N) is represented in figure 1.

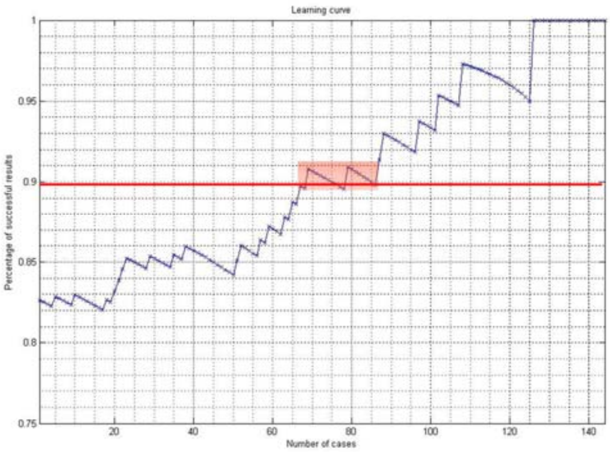

Figure 1: Learning curve

The shadowed area (cases 67 to 85) is placed where the learning curve oscillates around the 90% of successful results (red line in figure 1). Any case taken from this area could be used as a valid ending of the learning curve.

Surgical time evolution

The surgical time evolution, as mentioned in [11], is represented in figure 2

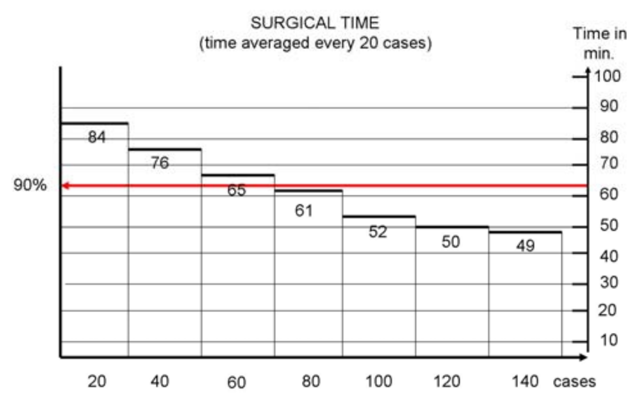

Figure 2: Surgical time evolution

In order to minimize the influence of the number of operated discs and the difficulty of every single case, the surgical time was averaged every 20 cases.

The optimal surgical time was taken as 45 minutes[1,2], so the control time[11] was also established at 45 minutes. As seen in figure 2, the asymptote is placed after case 80, so the optimal op.-time reached by the author for this limited number of cases was of approx. 50 min.

Patient outcome vs. surgical time evolution

The authors have superimposed the learning curve of patient outcome (see figure 1) with the averaged surgical time steps, (see figure 2). The optimal surgical time in the literature[1,2] is established at 45 min. for one single disc operation with a 0.9 (90%) of good and excellent results.
As the surgical time in this study was calculated for an average of 1.41 discs per case, the time scale was adjusted from 45 min. for one disc to 63.45 min. for 1.41 disc per operation in relation to 0.9 (90%) of good and excellent results, see red line in figure 2.

The surgical time is a general but not determining parameter that helps approximating the cutting point. The parameter of patient outcome contains the information about the final results and will therefore weigh more in the decision of placing the cutting point.

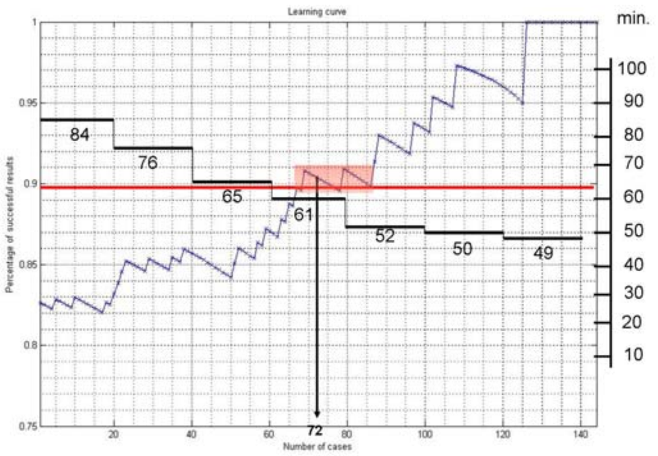

Figure 3: Learning curve superimposed with surgical time (black steps)

As can be seen in figure 3 the average surgical time (black steps) cuts the learning curve at the shadowed area around 90% of successful results, which contains case *N=72* (marked by an arrow in figure 3). The approximation with both parameters places the critical case number within the area after which the average surgical time stabilization begins.

Case 72 can be taken as a good approximation for the end of the learning effect (cases 67 to 85), as it is shown by both curves, and furthermore splits the 144 cases in two groups with the same number of samples.

Overall results

The overall results, using MacNab criteria, can be found in Table 3 and are graphically represented in Fig. 4.

Type of result	Number of cases	Percentage of cases
Excellent and good	119	82.64 %
Fair	20	13.89 %
Poor	5	3.47 %
Total	144	100 %

Table 3: Overall results

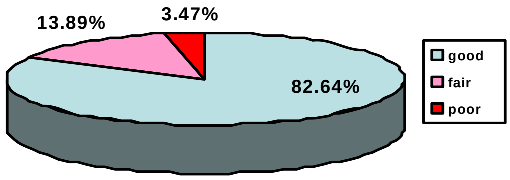

Figure 4: Overall results overview of the 144 cases

Analysis of surgical failures

25 patients out of 144 cases had a fair or poor result, as the clinical record or the feedback on the questionnaire was below the required qualification. These 25 fair and poor results were due to:

- *11 neuritis:* 10 of the neuritis were temporary dysesthesias that required medication for more than 1 week and less than 3 months. 1 case with drop foot syndrome who has recovered partially.
- *8 re-interventions caused by foraminal stenosis or residual fragments missed at surgery*. Five were open re-interventions and three were endoscopic re-interventions. Whether the fragment represented residual or recurrent herniation was not always clear, but was deemed residual if sciatica was not completely resolved post-operatively.
- *2 cases of sterile discitis* (unknown origin)
- *1 underestimated spinal stenosis*
- *3 instabilities* underestimated at patient selection.

Rehabilitation

Of the 144 cases, 90 underwent rehabilitation under direct supervision of the senior author. 43 were treated in other locations, but keeping periodical contact with the senior author.

For 11 cases the author did not have feedback on rehabilitation. From these 11 cases, 7 were considered as failed surgery, as the patients answered the questionnaire in a negative way or did not answer it at all.
In the resting 4 cases the patients answered the questionnaire in a positive way.

Thus the overall follow-up rate was of 92.36%. The average follow-up was of 24.24 months with a standard deviation of 13.32 months.

The follow-up and the questionnaire were evaluated for every patient by an independent group of professional physiotherapists.

Split results

The authors proceeded to split the results of the 144 patients around case 72, resulting in two groups of 72 cases each.

The results according to MacNab for the cases 1 to 72 (group 1) and for the cases 73 to 144 (group 2) can be found in Table 4.

Result type	Number of cases group 1	Percentage of cases group1	Number of cases group 2	Percentage of cases group 2
good/excellent	54	75 %	65	90.28 %
fair	13	18.05 %	7	9.72 %
poor	5	6.95 %	0	0 %

Table 4: Results for Group1 and Group 2

The distribution of results for both groups can be found in Figure 5.

Figure 5: Distribution of results in the two groups

Distribution of the complications found in the two groups:
Cases 1 to 72 (Group 1):
8 neuritis (1 with drop foot syndrome), 5 open reinterventions caused by foraminal stenosis or residual fragment, 2 discitis (unknown origin), 3 endoscopic reinterventions caused by residual fragment,
Cases 73 to 144 (Group 2):
3 neuritis, 1 spinal stenosis, 3 instabilities.

Discussion

Both groups had surgery under the same conditions, including the same operation room, equipment and surgical instruments.
Extruded herniations causing radiculopathy[1,2] and L5-S1 level were not excluded, in contrast to previously published articles[4, 6, 9] using first generation endoscopes.

The age averages of both groups are similar, see Table 5.

	Group 1: Cases 1 to 72	Group 2: Cases 73 to 144
Age average (in years)	45.49	45.43
Male	45	51
Female	27	21
Operated discs	112	92
One level surgery	36	55
Two level surgery	32	14
Three level surgery	4	3

Table 5: Discs, sex and age distribution

The factors that contributed to decrease the op-time in group 2 were less multi-level interventions (17 against 36) and a lower disc case rate (1.27 vs. 1.55 discs/case), see Table 5.
This time reduction and the improvement in the overall results from group 1 to group 2 are probably due to a more accurate diagnostic and a reduction of the procedure's aggressiveness and are therefore probably related to the surgeon's and his team's skill improvement.

Analysis of fair and poor results

The age average in the group of fair and poor results was 50 years, close to the overall age average.
The 1.48 discs/case rate of the group of fair and poor results was only slightly higher than the overall average of 1.41 discs/case.

The disc level distribution for the group of fair and poor results was of 13.52% for L3-L4 (5 discs), 43.24% for L4-L5 and 43.24% for L5-S1 (16 discs each) and 0% for L1-L2 and 0% for L2-L3.

The percentage of L5-S1 operated discs in the group of fair and poor results is slightly higher (5.49%) than in the overall disc level statistics, see Table 2, so L5-S1 can not be considered as a main cause to explain the poor and fair results.

As stated in [11] "Case mix sometimes complicates assessment of learning curves because as the surgeon becomes more experienced, the cases attempted become more difficult".
As the confidence of the surgeon handling this technique rose, cases which were rejected earlier were included and solved.

Factors that contributed to the improvement of the results

1) Less instrument manipulation during the procedure by optimal needle placement. Careful introduction of the dilator with greater attention made to its location in the cranial and lateral foraminal region to avoid irritation of the dorsal root ganglion.
2) Reduction of all exploration movements of the cannula to the minimum need.
3) Precise cannula configuration selection according to the anatomical region.
4) Better recognition of the patho-anatomy with identification of the damaged tissues. Reparation of annular tears and inflammatory membrane with radiofrequency.
5) Identification and cutting of the superior foraminal ligament, posterior longitudinal ligament and annular tissue if necessary. Proper bone foraminoplasty in foraminal stenosis[12,10].
6) Selective and direct approach for reaching the herniation. Correction of the entry point and angle depending on location of herniation.
   Central herniation: more lateral entry and horizontal needle direction.
   Foraminal herniation: more medial entry and vertical needle direction.
   If better access is needed (specially level L5-S1) foraminoplasty is required.

The learning curve is hard (see slope of the learning curve, figure 1 and [13]) due to the complexity of the presented surgical endoscopic technique.

Patient selection improved as the surgeon became more experienced in interpretation of MRIs and correlating findings with the visualized patho-anatomy.
An important factor in the learning process was the improvement of the surgeon's capacity of adaptation to each single case and thus the right choice of the endoscopic instruments needed in function of unexpected factors like bleeding, small foramina, osteofyte ingrowth, inflammatory painful tissue, etc.

It took approx. 60 cases for confident identification of the exiting and traversing nerve roots. The ability to do a proper foraminoplasty took more than 80 cases.

The results after the learning curve (90.28% of excellent/good results for group 2) were similar to the results reported by other authors with larger series of cases with endoscopic procedure (e.g. Yeung 500 cases[3], 219 cases[2]).

Conclusions

A study of 144 cases of endoscopic disc surgery and a method to calculate its learning curve was presented. The learning curve is established around the first 72 cases. After the learning curve the technique reaches a success rate of 90.28%. This rate is comparable to that of other techniques like transcanal discectomy[4].
The endoscopic technique as described by Yeung[1-3] is less traumatic then the open technique and provides an easier approach with a more direct access, specially to the high lumbar disc herniations and the foraminal and extraforaminal disc herniations, including the L5-S1 disc space.

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