Essentials in Ophthalmology
G. K. Kriegstein R. N. Weinreb
Series Editors

Glaucoma
Cataract and Refractive Surgery
Uveitis and Immunological Disorders
Vitreo-retinal Surgery
Medical Retina
Oculoplastics and Orbit
Pediatric Ophthalmology, Neuro-Ophthalmology, Genetics
Cornea and External Eye Disease
Vitreo-retinal Surgery
Editors  Stanislao Rizzo
         Fabio Patelli
         David R. Chow

Vitreo-retinal Surgery

With 50 Figures, Mostly in Colour
and 12 Tables

Springer
The Essentials in Ophthalmology series represents an unique updating publication on the progress in all subspecialties of ophthalmology.

In a quarterly rhythm, eight issues are published covering clinically relevant achievements in the whole field of ophthalmology. This timely transfer of advancements for the best possible care of our eye patients has proven to be effective. The initial working hypothesis of providing new knowledge immediately following publication in the peer-reviewed journal and not waiting for the textbook appears to be highly workable.

We are now entering the third cycle of the Essentials in Ophthalmology series, having been encouraged by readership acceptance of the first two series, each of eight volumes. This is a success that was made possible predominantly by the numerous opinion-leading authors and the outstanding section editors, as well as with the constructive support of the publisher. There are many good reasons to continue and still improve the dissemination of this didactic and clinically relevant information.

G.K. Krieglstein
R.N. Weinreb
Series Editors
September 2008
“All progress occurs because people dare to be different”.  

Harry Milner

Every so often, changes occur in the technology of our day-to-day lives that truly alter how we do things. As retinal surgeons, the development of sutureless vitrectomy systems is one of these revolutionary changes that have altered how most of us perform surgery. Since Dr Eugene de Juan introduced us to a 25-gauge transconjunctival sutureless cannula system, there has been almost a dizzying pace of change in our field, as instrumentation companies refine and improve the 25-gauge experience. Given some of the early limitations of 25-gauge technologies, Dr Claus Eckardt introduced us to an alternative, a 23-gauge sutureless cannula system, which is becoming increasingly popular. At the present time, there is considerable debate and confusion amongst our community about the direction our field is going to take. Are we all going to become 23-gauge surgeons? Will 20-gauge vitrectomy disappear? Can technologic improvements make the 25-gauge experience easier? We have put together this textbook to try and answer some of these questions, and to give you some help on when and how these new sutureless vitrectomy systems can be used. To aid us in this endeavour, we have recruited the leading surgeons in our field to offer their insights into the sutureless techniques they perform. We think you will enjoy the practical approach that many of the authors have taken in their chapters, and the “surgical tips” that are offered that can be used in your operating room right away.

Enjoy the textbook!

Stanislao Rizzo
Fabio Patelli
David R. Chow
September 2008
Chapter 1
Historical Overview of Microincision Surgery
A.J. Augustin

1.1 Introduction .................................................. 1
1.2 Pros and Cons of 25-Gauge Vitrectomy Systems .......... 3
References .......................................................... 7

Chapter 2
25-Gauge Instrumentation: Engineering Challenges and Tradeoffs
A.C. Barnes, C.M. DeBoer, P.R. Bhadri, O. Magalhaes Jr., R.M. Kerns, M.T. McCormick, L.P. Chong, M.S. Humayun

2.1 Introduction .................................................. 9
2.2 Microcannula System ........................................ 9
2.3 Entry ................................................................ 11
2.4 Infusion ............................................................ 13
2.5 Fluid Dynamics Sidebar ..................................... 14
2.6 Vitreous Cutter .................................................. 16
2.6.1 Drive Mechanism .......................................... 17
2.6.2 Flow Rate ....................................................... 19
2.7 Traction ............................................................. 19
2.8 Illumination ....................................................... 20
2.8.1 Terminology .................................................. 21
2.8.2 System Approach .......................................... 21
2.8.3 Power Supply Module ................................... 22
2.8.4 Illumination Source ....................................... 22
2.8.5 Optical System .............................................. 23
2.8.6 Optical Fiber ............................................... 24
2.8.7 System Loss ................................................. 25
2.8.8 System Compatibility ..................................... 27
2.9 Instrument Rigidity .......................................... 27
2.10 Discussion ....................................................... 28
References ............................................................ 29

Chapter 3
25-Gauge, Sutureless, Trans-Conjunctival Vitrectomy
S. Charles

3.1 Introduction ................................................... 31
3.2 Surgical Indications .......................................... 31
3.3 Wound Construction ......................................... 32
3.4 Fluidics ............................................................ 33
3.5 Cutter Design Issues ......................................... 33
3.6 Tool and Visualization Tradeoffs ........................ 34
3.7 Tool Flexion ..................................................... 34
3.8 20/25 Vitrectomy ............................................. 34
3.9 Visualization ..................................................... 35
3.10 Wound Leak Issues ......................................... 35
3.11 Cannula Withdrawal and Wound Closure ............... 36
References ............................................................ 36

Chapter 4
Transconjunctival 23-Gauge Vitrectomy
C. Eckardt

4.1 Placement of the Microcannulas: Two-Step Technique .... 37
4.2 Placement of the Microcannulas: One-Step Technique ... 38
4.3 Course of the Scleral Tunnel Incision ......................... 38
4.4 Instrumentarium .............................................. 39
4.5 Combined Phacoemulsification/ Vitreoretinal Surgery .... 40
4.6 Scleral Indentation ............................................ 40
4.7 Silicone Oil Injection and Removal ........................ 40
4.8 Removal of the Microcannulas ............................ 41
4.9 23-g Vitrectomy Compared to Conventional 20-g Vitrectomy 41
References ............................................................ 41
Chapter 8
25-Gauge Vitreous Surgery: Getting Started
C.C. Awh

8.1 Introduction .......................................................... 69
8.2 Case Selection .................................................... 70
8.3 Preoperative Preparation ......................................... 70
8.3.1 Anesthesia ..................................................... 70
8.4 Intraoperative Considerations ................................. 71
8.4.1 Cannula Insertion ............................................. 71
8.4.2 Instrument Insertion, Manipulation, and Removal ....... 71
8.4.3 Instrument Manipulation ...................................... 72
8.4.4 Visualization .................................................. 72
8.4.5 Illumination ................................................... 72
8.4.6 Fluidic Considerations ....................................... 73
8.4.7 Membrane Peeling ........................................... 74
8.4.8 Concluding the Case ......................................... 74
8.5 Postoperative Management ....................................... 75
8.5.1 Postoperative Antibiotics and Dressing .................. 75
8.5.2 Postoperative Examination ................................. 75
8.6 Conclusion .......................................................... 76
References ................................................................ 76

Chapter 9
25-Gauge Macular Surgery: Principles and Instrumentations
Y. Oshima, Y. Tano

9.1 Introduction .......................................................... 77
9.2 Principles of 25-Gauge Macular Surgery ..................... 77
9.2.1 Preoperative Examination, Considerations, and Informed Consent ........................................... 77
9.2.2 Surgical Procedures for 25-Gauge Macular Surgery ......................................................... 78
9.2.3 Nonvitrectomizing Vitreous Surgery for ERM Removal Using the 25-Gauge System ................. 80
9.2.4 Internal Limiting Membrane (ILM) Peeling .................. 81
9.2.5 Submacular Surgery ........................................... 81
9.3 25-Gauge Instrumentation and Devices for Macular Surgery .............................................. 82
9.3.1 Basic Instruments .............................................. 82
9.3.2 Special Instruments and Devices for Macular Surgery ...................................................... 82
References ................................................................ 82

Chapter 7
Comparison of 25-Gauge Trocar/Cannula Wound Healing and Remodeling with In Vivo Vitrector Flow Analysis
P.J. Ferrone

References ................................................................ 66

Chapter 6
Small Gauge Vitrectomy: Anesthesia, Incision Technique and Cannula Removal
S. Rizzo, F. Genovesi-Ebert, F. Patelli

6.1 Introduction .......................................................... 49
6.2 Anesthesia ........................................................... 50
6.3 Surgical Technique ................................................ 50
6.3.1 25-Gauge Trocar Insertion Techniques .................... 50
6.3.2 23-g Trocars Insertion Techniques .......................... 52
6.3.3 Insertion of the 25–23-Gauge Chandelier ................. 54
6.3.4 Complications of Trocar Insertion ......................... 54
6.3.7 Cannula Removal ............................................... 55
References ................................................................ 55

Chapter 5
23-Gauge One-Step Instrumentation
S. Rizzo, M. Palla

5.1 Introduction .......................................................... 45
5.2 Trocar ................................................................. 45
5.3 Vitrectome ............................................................ 45
5.4 Endoilluminator and Endolaser ............................... 47
5.5 Summary ............................................................. 48

Chapter 8
25-Gauge Vitreous Surgery: Getting Started
C.C. Awh

8.1 Introduction .......................................................... 69
8.2 Case Selection .................................................... 70
8.3 Preoperative Preparation ......................................... 70
8.3.1 Anesthesia ..................................................... 70
8.4 Intraoperative Considerations ................................. 71
8.4.1 Cannula Insertion ............................................. 71
8.4.2 Instrument Insertion, Manipulation, and Removal ....... 71
8.4.3 Instrument Manipulation ...................................... 72
8.4.4 Visualization .................................................. 72
8.4.5 Illumination ................................................... 72
8.4.6 Fluidic Considerations ....................................... 73
8.4.7 Membrane Peeling ........................................... 74
8.4.8 Concluding the Case ......................................... 74
8.5 Postoperative Management ....................................... 75
8.5.1 Postoperative Antibiotics and Dressing .................. 75
8.5.2 Postoperative Examination ................................. 75
8.6 Conclusion .......................................................... 76
References ................................................................ 76
## Chapter 11
### Small-Gauge Vitrectomy for Retinal Detachment
F. Patelli, P. Radice

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.1 Historical Perspective</td>
<td>105</td>
</tr>
<tr>
<td>11.2 Uncomplicated Primary Rhegmatogenous Retinal Detachment</td>
<td>105</td>
</tr>
<tr>
<td>11.2.1 Small-Gauge Vitrectomy vs Scleral Buckle</td>
<td>105</td>
</tr>
<tr>
<td>11.2.2 Surgical Technique</td>
<td>106</td>
</tr>
<tr>
<td>11.3 Complicated Rhegmatogenous Retinal Detachment</td>
<td>109</td>
</tr>
<tr>
<td>11.3.1 Small-Gauge vs 20-Gauge Vitrectomy</td>
<td>109</td>
</tr>
<tr>
<td>11.4 Conclusion</td>
<td>109</td>
</tr>
<tr>
<td>References</td>
<td>110</td>
</tr>
</tbody>
</table>

## Chapter 12
### Perfluorocarbon-Perfused 25-Gauge Vitrectomy
G. Garcia-Aguirre, H. Quiroz-Mercado

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1 Physical and Chemical Characteristics of Perfluorocarbon Liquids</td>
<td>111</td>
</tr>
<tr>
<td>12.2 History</td>
<td>111</td>
</tr>
<tr>
<td>12.3 Uses of Perfluorocarbon Liquids in Vitreoretinal Surgery</td>
<td>111</td>
</tr>
<tr>
<td>12.4 Ocular Toxicity of Perfluorocarbon Liquids</td>
<td>112</td>
</tr>
<tr>
<td>12.5 Perfluorocarbon-Perfused Vitrectomy</td>
<td>112</td>
</tr>
<tr>
<td>12.6 Perfluorocarbon-Perfused 25-Gauge Vitrectomy (PCP25GV): Technique</td>
<td>113</td>
</tr>
<tr>
<td>12.6.1 Preparation for Vitrectomy</td>
<td>113</td>
</tr>
<tr>
<td>12.6.2 Core Vitrectomy</td>
<td>113</td>
</tr>
<tr>
<td>12.6.3 Posterior Hyaloid Separation</td>
<td>114</td>
</tr>
<tr>
<td>12.6.4 Membrane Peeling and Dissection</td>
<td>114</td>
</tr>
<tr>
<td>12.6.5 Additional Procedures</td>
<td>114</td>
</tr>
<tr>
<td>12.6.6 Fluid–Air Exchange</td>
<td>114</td>
</tr>
<tr>
<td>12.6.7 Closing</td>
<td>115</td>
</tr>
<tr>
<td>12.7 Advantages of Performing Perfluorocarbon-Perfused Vitrectomy with 25-Gauge Instruments</td>
<td>115</td>
</tr>
<tr>
<td>12.8 Complications</td>
<td>116</td>
</tr>
<tr>
<td>12.9 Conclusion</td>
<td>116</td>
</tr>
<tr>
<td>References</td>
<td>116</td>
</tr>
</tbody>
</table>

## Chapter 13
### Primary 25-Gauge Vitrectomy with Topical Anesthesia for Persistent Vitreous Floaters
G. Garcia-Aguirre, V. Morales-Canton, H. Quiroz-Mercado

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.1 Introduction</td>
<td>119</td>
</tr>
<tr>
<td>13.2 History</td>
<td>119</td>
</tr>
<tr>
<td>13.3 Surgical Trends</td>
<td>119</td>
</tr>
<tr>
<td>13.4 Advantages of 25-Gauge Vitrectomy</td>
<td>119</td>
</tr>
<tr>
<td>13.5 Patient Selection</td>
<td>120</td>
</tr>
<tr>
<td>13.6 Technique</td>
<td>120</td>
</tr>
<tr>
<td>13.6.1 Variation with 2-Port Vitrectomy</td>
<td>120</td>
</tr>
<tr>
<td>13.7 Complications</td>
<td>121</td>
</tr>
<tr>
<td>13.8 Conclusion</td>
<td>121</td>
</tr>
<tr>
<td>References</td>
<td>121</td>
</tr>
</tbody>
</table>
Chapter 19
Combined Phaco/25-Gauge Vitrectomy
F. Genovesi-Ebert, S. Rizzo, M. Palla

Chapter 20
Complications of 25-Gauge Vitrectomy
A. Gupta, S.D. Schwartz

Chapter 21
A Comparison of 20- vs 25-Gauge Vitrectomy:
Does Size Matter?
C.A. McCannel

Chapter 22
20-Gauge Sutureless Vitrectomy Trocar System
C. Claes, A. Lafeta

Chapter 23
20-Gauge Non-Cannulated Sutureless Vitrectomy
D.R. Chow, D. Polya

Chapter 24
Small-Gauge Vitrectomy: Which Calliper Should We Choose and When?
S. Rizzo, F. Genovesi-Ebert, F. Patelli

Chapter 25
Current Clinical Data and Future
(for Small-Gauge Vitreoretinal Surgery)
S. Binder, B. Wimpissinger, L. Kellner
Chapter 25
Instruments and Efficiency ........................................................... 214
Need for Sutures ........................................................................... 214
Intraocular Pressure ..................................................................... 214
Choroidal Detachment ............................................................... 215
Vitreous Hemorrhage ................................................................. 215
Endophthalmitis .......................................................................... 215
Retinal Detachment and Retinal Breaks ........................................ 216
Vitreous Incarceration .................................................................. 216
Macular Edema ............................................................................ 216
Corneal Topography .................................................................... 217
Visual Acuity ................................................................................ 217
23-Gauge Vitrectomy ................................................................... 217
Surgical Technique ....................................................................... 217
Need for Sutures .......................................................................... 217
Intraocular Pressure ..................................................................... 218
Complications ............................................................................... 218
Endophthalmitis .......................................................................... 218
Retinal Tears and Retinal Detachment ......................................... 218
Use of Silicone Oil ....................................................................... 218
Topical Anaesthesia ...................................................................... 218
The Future ..................................................................................... 218
References .................................................................................... 219

Chapter 26
Pearls from Experts
M. Ohji, S. Huang, P. Kaiser, P. Tornambe, S. Gotzaridis

26.1 25-Gauge System ................................................................. 223
Displacing the Conjunctiva ......................................................... 223
Lower Aspiration .......................................................................... 223
Bright Illumination ....................................................................... 223
Instrument Flexibility ................................................................... 223
Simultaneous Cataract Surgery ................................................... 225
Preventing Fluid Leakage ............................................................ 226
Case Selection .............................................................................. 226
Contact Lenses ............................................................................ 226
25-Gauge System ................................................................. 227
23-Gauge System ................................................................. 227
Preventing Fluid Leakage ............................................................ 226
Case Selection .............................................................................. 226
Contact Lenses ............................................................................ 226
S. Huang

26.2 25-Gauge System ................................................................. 227
23-Gauge System ................................................................. 228
S. Kaiser

26.3 25-Gauge System ................................................................. 227
P. Tornambe

26.4 23-Gauge System ................................................................. 228
S. Gotzaridis

26.5 20-Gauge Sutureless System ............................................... 229

Index ......................................................................................... 231
Contributors

F. Altomare
Department of Ophthalmology and Vision Sciences
University of Toronto, Toronto
ON, Canada
and
Department of Ophthalmology
St. Michael’s Hospital, Toronto
ON, Canada
and
Department of Ocular Oncology
Princess Margaret Hospital
University Health Network, Toronto
ON, Canada

J. Fernando Arevalo
Professor and Chairman
Retina and Vitreous Service
Clinica Oftalmológica Centro Caracas
The Arevalo-Coutinho Foundation for Research in Ophthalmology
Caracas, Venezuela

A. Augustin
Direktor der Augenklinik
Moltkestrasse 90
76133 Karlsruhe

C.C. Awh
Retina-Vitreous Associates
Baptist North Medical Office Bldg.
2011 Murphy Avenue, Suite 603
Nashville, TN 37203
USA

Aaron Barnes
Eye Concepts, Doheny Eye Institute
University of Southern California
1450 San Pablo Street, DEI 1900
Los Angeles, CA, USA – 90033

Prashant Bhadri
Eye Concepts, Doheny Eye Institute
University of Southern California
1450 San Pablo Street, DEI 1900
Los Angeles, CA, USA – 90033

S. Binder
Department of Ophthalmology
The Ludwig Boltzmann Institute for Retinology
and Biomicroscopic Lasersurgery
Rudolf Foundation Clinic
Juchgasse 25 A-1030, Vienna, Austria

A. Capone
1493 Fairfax Street
Birmingham, MI 48009, USA

S.T. Charles
Charles Retina Institute
6401 Poplar Avenue, Suite 190
Memphis, TN 38119, USA

Lawrence Chong
Eye Concepts, Doheny Eye Institute
University of Southern California
1450 San Pablo Street, DEI 1900
Los Angeles, CA, USA – 90033

D.R. Chow
University of Toronto
23 Ivor Road, North York, Ontario M4N 2H3
Canada

C. Claes
Department of Vitreoretinal Surgery
St. Augustinus Hospital
Oosterveldlaan 24
Wilrijk-Antwerp 2610
Belgium

Charles DeBoer
Eye Concepts, Doheny Eye Institute
University of Southern California
1450 San Pablo Street, DEI 1900
Los Angeles, CA, USA – 90033

C. Eckardt
Augenklinik
Staedtische Kliniken
Frankfurt, 65929
Germany
Contributors

P. J. Ferrone
600 Northern Blvd.
Suite 216
Great Neck, NY 11021, USA

William R. Freeman
Jacobs Retina Center
Shiley Eye Center
University of California San Diego
La Jolla, CA
USA

G. Garcia-Aguirre
Retina Department
Hospital “Dr. Luis Sanchez Bulnes”
Asociacion para Evitar la Ceguera en Mexico
Vicente Garcia Torres 46
San Lucas Coyoacan 04030
Mexico City, Mexico

F. Genovesi-Ebert
Eye Surgery Clinic
Santa Chiara Hospital
Via Roma, 67
56100 Pisa
Italy

Stratos Gotzaridis
66 Vas. Sophias Av.
Athens 115 28
Greece

A. Gupta
Jules Stein Eye Institute, David Geffen
School of Medicine at UCLA
Los Angeles, CA, USA

T. S. Hassan
Associated Retinal Consultants, PC
3535 W. 13 Mile Road
Suite 632
Royal Oak, MI 48073
USA

Suber Huang
Professor and Vice-Chairman
Director, Center for Retinal and Macular Disease
Department of Ophthalmology and Visual Sciences
University Hospitals Eye Institute/Case Western Reserve University
11100 Euclid Avenue, Lakeside 4115
Cleveland, Ohio 44106, USA

Mark Humayun
Eye Concepts, Doheny Eye Institute
University of Southern California
1450 San Pablo Street, DEI 1900
Los Angeles, CA, USA – 90033

Peter K. Kaiser
Director, Digital OCT Reading Center
Staff, Cole Eye Institute
Cleveland Clinic
9500 Euclid Avenue, Desk i3
Cleveland, OH 44195

L. Kellner
Department of Ophthalmology
The Ludwig Boltzmann Institute for Retinology and Biomicroscopic Lasersurgery
Rudolf Foundation Clinic, Juchgasse 25 A-1030
Vienna, Austria

Ralph Kerns
Eye Concepts, Doheny Eye Institute
University of Southern California
1450 San Pablo Street, DEI 1900
Los Angeles, CA, USA – 90033

M. Kickinger
Rua Coronel Paulo Malta Rezende, 35/2006 - Barra da Tijuca
Rio de Janeiro, RJ - 22631-005
Brazil

A. Lafeta
Vitreo-Retinal Department,
Sint-Augustinus Hospital, Wilrijk
Belgium

Octaviano Magalhaes
Eye Concepts, Doheny Eye Institute
University of Southern California
1450 San Pablo Street, DEI 1900
Los Angeles, CA, USA – 90033

C. A. McCannel
Mayo Foundation for Medical Education and Research
200 First Street SW
Rochester, MN 55905, USA

Matthew McCormick
Eye Concepts, Doheny Eye Institute
University of Southern California
1450 San Pablo Street, DEI 1900
Los Angeles, CA, USA – 90033

V. Morales-Canton
Director Retina Department
Hospital “Dr. Luis Sanchez Bulnes”
Asociacion para Evitar la Ceguera en Mexico
Vicente Garcia Torres 46
San Lucas Coyoacan 04030
Mexico City, Mexico
M. Ohji
1-4-33 Aoshinke
Mino 562-0024, Japan

Y. Oshima
Department of Ophthalmology
Osaka University Medical School
Osaka
Japan

M. Palla
Eye Surgery Clinic
Santa Chiara Hospital
Via Roma, 67
56100 Pisa, Italy
and
U.O. Chirurgia Oftalmica
S. Chiara Hospital
Azienda Ospedaliero-Universitaria
Pisana via Roma
Pisa
Italy

M. Palla
Eye Surgery Clinic
Santa Chiara Hospital
Via Roma, 67
56100 Pisa, Italy

P. Radice
Department of Ophthalmology
Vitreoretinal Service
Ophthalmic Hospital “fatebenefratelli”
Milan, Italy

F.A. Rezende
Rua Humaitá, 244/1202 - bloco 2 - Humaitá
Rio de Janeiro, RJ - 22261-001
Brazil

S. Rizzo
Professor and Chairman of Ophthalmology
Eye Surgery Clinic
Santa Chiara Hospital
Via Roma, 67
56100 Pisa, Italy

Juan G. Sanchez
Retina and Vitreous Fellow
Retina and Vitreous Service
Clinica Oftalmológica Centro Caracas
The Arevalo-Coutinho Foundation for Research in Ophthalmology
Caracas, Venezuela

S.S.D. Schwartz
Department of Ophthalmology
Jules Stein Eye Institute
100 Stein Plaza
Los Angeles, CA 90095
USA

T.M. Soe
Department of Ophthalmology
Osaka University Medical School
Osaka, Japan

Y. Tano
Professor of Ophthalmology
Osaka University Medical School
Osaka, Japan

Paul Tornambe
12630 Monte Vista Rd #104
Poway, California
USA 92064

B. Wimpissinger
Department of Ophthalmology
The Ludwig Boltzmann Institute for Retinology
and Biomicroscopic Lasersurgery
Rudolf Foundation Clinic
Juchgasse 25 A-1030
Vienna, Austria
Core Message

- Ever since the introduction of pars plana vitrectomy, the development of vitrectomy systems has been directed towards ever smaller and at the same time ever more efficient instruments.
- Especially the accelerated progress seen in the development of the 25-gauge and 23-gauge vitrectomy systems over the last 5 years, contributed to shortened intervention times and low-profile invasive interventions, affording shorter rehabilitation times and less postoperative discomfort.
- In spite of its considerably widened range of applications, 25-gauge vitrectomy to-date continues to be associated with certain disadvantages: the high flexibility and delicate nature of 25-gauge instruments require specific prior training on the part of the surgeon, while rendering some surgical manipulations altogether impossible.

For these reasons, and also in view of its reduced flow rate, 25-gauge vitrectomy is still not an option for all applications and is not an all-purpose vitrectomy system, which means that in addition to the 25-gauge instrumentarium surgeons should always have access to a 20-gauge system (added costs/logistics).

- By comparison with 25-gauge instruments, the 23-gauge system provides distinctly higher instrument stability and increased flow rates – while permitting transconjunctival access at the same time.

- The 23-gauge system thus combines the benefits of the 25-gauge and the 20-gauge systems; it attains an application range of almost 100%, and as a result may become the new standard in vitrectomy.

1.1 Introduction

The last decade has seen a general trend toward efficient, minimal invasive interventions in several areas of medicine [12, 13, 17, 23]. Ever since the introduction of pars plana vitrectomy over 30 years ago, the instrumentarium of posterior segment surgery, too, has been subject to incessant change (Table 1.1). In this, two objectives have been in the foreground: one is reducing surgery times, and the other speeding the recovery of the eye. The primary means of reaching these targets lies in instruments that are smaller – and thus induce less surgical trauma – and at the same time more efficient, while affording improved visualization and illumination of the operating field. On the other hand, the minimization of the instrument diameter and the smaller lumen going with it may have a counterproductive effect on the functionality and efficiency of vitrectomy instruments. For according to Poiseuille's Law the volume flow rate along a pipe is directly proportional to the fourth power of the pipe's radius. When reducing the instrument diameter it is, therefore, to be remembered that the infusion and aspiration rates obtained with this instrument also will be reduced. General improvement or advancement of the instrumentarium has thus relied on balancing the requirements for reduced diameter and the performance of an instrument. The outer diameter of vitrectomy instruments, and others, is given in “gauge” which is derived from the US-American unit for wires, the American wire gauge (AWG). The gauge numbering relates to the number of drawing operations necessary to produce a wire of a desired diameter. This means the thinner the desired wire, the more passes through the drawing dies are needed and the higher the gauge number. The gauge number also corresponds to the number of wires going into one square centimeter. In other words: the higher the gauge number, the smaller the outer diameter of an instrument (see Table 1.2). According to Poiseuille's Law, lower infusion and aspiration rates have to be taken into account when high-gauge instruments (i.e., smaller...
instrument diameters) are being used and this, in turn, may affect their functionality and efficiency.

Ever smaller instrument diameters have been designed since the early days of “pars plana vitrectomy” in the 1970s, when Machemer, closely followed by Klöti, relocated the access for vitreous removal to the pars plana area to preserve the crystalline lens [16, 24]. While Machemer et al. [25] started out by developing a 17-gauge instrument, i.e., the vitreous infusion suction cutter (VISC), that still needed a 2.3-mm sclerotomy port, two decisive advancements were introduced as early as in 1974: for the first time it was now possible to reduce instrument diameters to a marked degree by separating the infusion system and the cutting system. The 20-gauge vitrectomy system (0.9-mm diameter) was born, with infusion, vitrectome and illumination being introduced into the pars plana via three separate ports. Interestingly, splinting to protect the scleral incisions and facilitate instrument change had been propagated already in those days – this concept has been reintroduced, and today is applied to the microtrocar cannulas of the 25-gauge and 23-gauge systems [16].

### Table 1.1. Milestones of pars plana vitrectomy

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early 1970s</td>
<td>Machemer and Klöti both have the idea of shifting the site of vitrectomy access to the pars plana area in an effort to preserve the lens. “Birth of pars plana vitrectomy”</td>
</tr>
<tr>
<td>1974</td>
<td>O’Malley and Heintz introduce the 20-gauge vitrectomy system, today’s “gold standard”</td>
</tr>
<tr>
<td>1974</td>
<td>Klöti recommends the use of guiding cannulas — the precursors of microcannulas — for ease of and added eye protection during instrument change.</td>
</tr>
<tr>
<td>1990</td>
<td>de Juan and Hickingbotham present first 25-gauge vitrectomy set, and recommend its use in pediatric interventions in particular</td>
</tr>
<tr>
<td>1995</td>
<td>At the ARVO meeting, Singh et al. present a 23-gauge vitrectomy system whose use, however, clearly is restricted to specific office-based interventions</td>
</tr>
<tr>
<td>2002</td>
<td>Fujii et al. present first fully integrated 25-gauge system, consisting of microtrocar cannulas, vitrectome and infusion, and demonstrate its safety and efficiency, especially in “simple” vitrectomies</td>
</tr>
<tr>
<td>2004/2005</td>
<td>Eckardt introduces first fully integrated 23-gauge vitrectomy system, and demonstrates its safety and efficiency</td>
</tr>
<tr>
<td>Up to 2007</td>
<td>Ongoing enhancement of instrumentation and ranges of application for the 25-gauge and 23-gauge systems</td>
</tr>
</tbody>
</table>

### Table 1.2. Cannula gauge numbers and corresponding outer diameters

<table>
<thead>
<tr>
<th>Gauge</th>
<th>Outer diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17-G</td>
<td>2.3</td>
</tr>
<tr>
<td>19-G</td>
<td>1.1</td>
</tr>
<tr>
<td>20-G</td>
<td>0.9</td>
</tr>
<tr>
<td>23-G</td>
<td>0.6</td>
</tr>
<tr>
<td>25-G</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Summary for the Clinician

- The outer diameter of the instruments is given in gauge numbers, in a seemingly counterintuitive fashion: the higher the gauge number, the smaller the diameter.
- The 20-gauge vitrectomy system has been considered the "gold standard" since 1974; the last 5 years, in particular, have seen fast-paced innovation in the field of the posterior segment instrumentarium, directed toward smaller, more efficient 25-gauge and 23-gauge vitrectomy systems.
- However, when reducing the instrument diameter, it is to be remembered that flow rates also will be reduced (Poiseuille's Law), which may affect the functionality and performance of the instruments.
- It needs to be ensured, therefore, that the performance of instruments with reduced diameters at least equals that of the well-established 20-gauge system.

1.2 Pros and Cons of 25-Gauge Vitrectomy Systems

De Juan and Hickingbotham developed a 25-gauge instrument set for pediatric use already in 1990, since the "conventional" 20-gauge vitreous cutters had proven to be big and lacking in precision, especially in children [7, 42]. This first 25-gauge instrument set, which consisted of just a pneumatic vitrectome, scissors, and a manipulator for membrane removal, at first was used mainly in pediatric surgery, to allow for higher precision and permit controlled operation even in difficult maneuvers in that particular field [6]. De Juan and Hickingbotham explicitly stated in their publication that due to its reduced aspiration rate the 25-gauge vitrectome was to be used solely in selected, delicate cases requiring particularly precise and careful intervention. It was 12 years later, when eventually a complete 25-gauge vitrectomy system was introduced by Fuji et al. [10] which consisted of microtrocar cannulas, affording ease and safety of instrument introduction and withdrawal, as well as an array of integrated 25-gauge instruments. Due to their small diameter (0.5 mm), 25-gauge cannulas allow transconjunctival introduction, thus avoiding the time-consuming preparation of the conjunctiva that is required in conventional 20-gauge sclerotomies. Using a trocar with forceps, the conjunctiva, in this procedure, is pulled back a little prior to inserting the cannula, and this displacement provides a slight stagger of the wounds in the sclera and conjunctiva in relation to each other. In 25-gauge vitrectomy, the trocar is introduced perpendicularly to the sclera, i.e., it is directed to the center of the eye. This does not, in fact, create a two-step self-sealing wound. But since the conjunctiva will slip back to its more anterior position, where it is bound to cover the sclerotomy and probably provides a temporary tamponade to the opening – and also in view of the small sclerotomy diameter – no suturing should be required.

As already described, Poiseuille's Law (see above) indicated that the infusion and aspiration rates obtained by the 25-gauge system would be distinctly lower than those of the 20-gauge system. This was confirmed by Fuji et al. [10] in their first evaluation study of the 25-gauge system, where they established markedly reduced infusion and aspiration rates as against the 20-gauge system. To ensure sufficient aspiration rates also for the 25-gauge system, high vacuum settings (500 mmHg) should be used with this system, together with high cutting rates (1,500 cpm), so that optimum tissue fragmentation is guaranteed and "plugging" of the 25-gauge vitrectome is prevented. While the 25-gauge vitrectomy system principally is considered safe and efficient, opinions on the integrity of the sutureless 25-gauge sclerotomies are at variance [11, 15, 18, 19, 35, 36, 43]. Only recently, a modified incision technique was recommended to improve the integrity of sutureless 25-gauge sclerotomies [22, 37]. No significant difference has been identified between 25-gauge vitrectomy and 20-gauge vitrectomy as regards postoperative complications [4, 15, 26–28, 35, 38]. Sutureless sclerotomies have been at the center of constant concern as regards an increased risk of postoperative endophthalmitis following 25-gauge vitrectomy; however, to date this has never been established [11, 15, 19, 21, 35, 43]. Interestingly, similar apprehensions have been expressed in connection with clear corneal incisions in cataract surgery, but despite some case reports [29, 40] again no increased rate of endophthalmitis could be confirmed.

Due to the limited instrumentarium and high flexibility of the instruments available in the first years, use of the 25-gauge system initially was restricted to "simple vitrectomies" such as removal of epiretinal membranes or macula surgery, procedures which in the opinion of some surgeons did not involve peripheral work or the removal of major vitreous portions [11, 15, 19]. It is controversially discussed and, in fact, even considered a main limitation of 25-gauge technology whether the deliberately accepted incompleteness of vitreous removal is at all sufficient in these indications, or may
even represent an increased hazard potential. More involved pathologies, demanding extensive removal of the vitreous, initially required the use of 20-gauge vitrectomy systems. Over recent years, widening the array of instruments (e.g., forceps, picks, and other manipulating devices, endolaser), better illumination systems, and specific improvement of the instruments – i.e., by increasing instrument stiffness – has contributed to finally broadening the application range of 25-gauge vitrectomy [31]. The use of silicone oil also was long considered a contraindication of the 25-gauge system [33], but meanwhile has been made possible by a 25/20-gauge hybrid system for silicone oil infusion [3]. While nowadays silicone oil may be infused through a 25-gauge sclerotomy, this process clearly prolongs surgery times.

Apart from this expanded range of applications, the increasing experience of surgeons as well as commercial aspects certainly contribute to the fact that 25-gauge technology to some extent is now being used in complicated findings such as proliferative vitreoretinopathy, diabetic retinopathy, and retinal detachment, i.e., in pathologies that require the removal of the peripheral vitreous or the complicated removal of membranes [33].

As before, however, 25-gauge vitrectomy is not suitable for all indications, and in these cases the surgeon must be able to resort to the 20-gauge system. This "dual equipment" is, of course, an additional and not trifling cost factor. On a whole, opinions on the applicability of the 25-gauge system vary widely: in a survey the “American Society of Retina Specialists” carried out in 2006, numerous surgeons (26.8%) stated that the 25-gauge system was a viable means in 26–50% of their cases [32]. On the other hand, almost as many surgeons (24%) feel the 25-gauge system can be used in only 11–25% of cases, while a further 22% of surgeons are of the opinion that they can use it in 51–75% of their cases. However, these data cannot be applied to Germany or Europe without difficulty, since in the US-American system the majority of procedures are carried out on an outpatient basis, and rapid patient recovery may rank higher than other aspects as compared with Germany/Europe.

25-gauge systems presently are available from two manufacturers (Alcon Laboratories, Ft. Worth, TX, USA; Bausch & Lomb, Rochester, NY, USA) and differ essentially in two aspects [31]. While the trocar of the first-generation 25-gauge system by Bausch & Lomb was developed on the principle of a hollow needle, which sometimes makes it difficult to introduce, the trocar of the Alcon 25-gauge system is based on a modified V-shaped stiletto blade, so that only a small amount of force is necessary for insertion [3]. The Bausch & Lomb vitrectome is operated electrically, while the Alcon vitrectome is pneumatically driven. Its low weight and resulting ease of handling is considered another advantage of the Alcon system [3].

There are two decisive benefits invariably mentioned in connection with the 25-gauge system, viz. faster patient rehabilitation and shorter surgery times. As a subjective assessment, most surgeons register more rapid patient rehabilitation or “less postoperative ocular trauma” following the application of a 25-gauge system [11, 15, 19, 35, 43]. It should be remembered, though, that shortened surgery times are primarily due to the fact that opening and closing the eye globe are considerably less time-consuming when a 25-gauge system is used, while vitreous removal is likely to take a little longer, because of the small lumen of the instrument [10]. In complicated procedures, requiring the extensive removal of vitreous, overall intervention time may actually be prolonged when using the 25-gauge system versus the 20-gauge system [11, 19].

In spite of its essentially positive aspects, certain limitations to the 25-gauge system persist to date. For instance, the higher flexibility and delicateness that is associated with 25-gauge instruments, against the considerably more stable 20-gauge (and 23-gauge) instruments, make specific surgeon training a prerequisite [3, 10, 15, 19]. Moreover, high instrument flexibility renders certain surgical maneuvers impossible or feasible only subject to limitations [15, 20]. While, for example, the 20-gauge instrument may be used to rotate the eye for a better view of the periphery, this is hardly, if at all, possible with a 25-gauge instrument [20]. This is bound to create problems for the removal of peripheral vitreous. Introduction of the microcannulas also has been known to be difficult in some cases. Some reports describe detachment of a 25-gauge cannula from the trocar, as well as damage and bending of the cannula during introduction, so that inserting and retrieving the delicate 25-gauge instruments presented distinctly more problems and sometimes resulted in warping of the instrument [2, 20].

The disadvantages of the 25-gauge described may not necessarily entail serious complications, but may be the cause of time-consuming procedures. The time saved in opening and closing the eye may subsequently have to be "wasted," for instance, on more intricate surgical manipulations, that may become necessary because of instrument flexibility, or on intraoperative problems such as workflow that are complicated by the loss or damage of cannulas and instruments, or because extensive removal of the vitreous with a 25-gauge systems makes considerably higher demands on time.
1.3 23-Gauge Vitrectomy Systems: The Future Gold Standard?

The accelerated efforts seen over the last 3 years in the development of a 23-gauge system designed to unite the benefits of the 20-gauge and the 25-gauge system were mainly driven by the limitations described for the 25-gauge system. Singh et al. [39] had, in fact, introduced a first electronic 23-gauge vitrectome as early as 1995, which they later complemented by a 23-gauge infusion system. This, however, was not a complete 23-gauge system providing a wide array of instruments, but just a portable system whose use was meant exclusively for vitreous biopsies and minor office-based interventions – as carried out mainly in the USA [5, 14]. Almost 10 years passed before a fully integrated 23-gauge vitrectomy system for routine clinical use had been designed: in 2005 Eckardt [8] in cooperation with DORC (The Netherlands) eventually introduced a complete 23-gauge instrumentarium and demonstrated its safety and efficiency in a first evaluation study. Presently, 23-gauge systems are available on a larger scale from four manufacturers: Alcon Laboratories (Ft. Worth, TX, USA; Figs. 1.2 and 1.3), DORC (The Netherlands), Oertli...
Figures 1.2 and 1.3 show a 23-gauge vitrectomy system as well as a 23-gauge instrument portfolio. 23-gauge instruments combine considerably higher stiffness and stability than 25-gauge instruments, with a diameter that is smaller than that of 20-gauge instruments; this permits them to be introduced into the eye through transconjunctival sutureless sclerotomies [8]. Unlike the 25-gauge trocars, 23-gauge trocars are not introduced perpendicular to the scleral surface, but at an angle, and instrumentation is brought to a vertical position in subsequent steps. This type of two-step access is designed to facilitate postoperative closure of the sclerotomies by intraocular pressure, ensuring higher integrity of wound closure than with 25-gauge sclerotomies. As early as 2005, Eckardt [8] was able to demonstrate that all 23-gauge sclerotomies were self-sealing and tight. Another very interesting and plausible method under anatomical physiological aspects was recently proposed by Rizzo et al., who suggested turning the blade by 30° or a little more. This wound configuration considers the course of the collagen fibers, which ensures even better wound closure [34]. Since 23-gauge instruments can be said to be similar to 20-gauge instruments for stiffness and stability, the training period for a surgeon when switching to 23-gauge is much shorter than with 25-gauge instruments, and might more aptly be termed a familiarizing phase. In addition, distinctly higher infusion and aspiration rates could safely be expected with the 23-gauge system than with the 25-gauge system (Poiseuille’s Law, see above), so that careful and extensive vitreous removal – which should continue to be the standard routine – would pose no problem when using the 23-gauge system. This is corroborated by the fact that, at a vacuum level of 600 mmHg and depending on the cutting rate, the same or even higher flow rates are obtained than with the 20-gauge system (Table 1.3). Thanks to higher flow rates plus increased instrument stability, the 23-gauge system may be employed in simple as well as in complicated vitrectomies, and thus is suitable for a wider application range than the 25-gauge systems. The application range of 23-gauge vitrectomy is almost identical to that of the 20-gauge system, while surgery times are shortened and interventions are less invasive [41]; it follows, therefore, that it does combine the benefits of the 25-gauge and 20-gauge systems. First experience suggests that solely the use of silicone oil may lead to sclerotomy leakage, so that in these cases sutures are required for wound closure. First experiments have been carried out investigating “dual-diameter” devices (23-gauge for infusion and illumination, 20-gauge for the working channel). While there is, of course, the advantage that surgeons can continue to use available 20-gauge systems, the potential benefits of the 23-gauge system (more rapid rehabilitation, no opening of the conjunctiva) are not turned to maximum profit.

The preliminary results and experience obtained with 23-gauge systems are extremely promising in principle, and with few exceptions 23-gauge vitrectomy may well be able to replace 20-gauge vitrectomy in the near future [9].

### Table 1.3. Comparison of different vitrectomies (20-, 23-, and 25-gauge) for cutting rates, inherent stability, as well as flow rates at given aspiration and cutting rates

<table>
<thead>
<tr>
<th></th>
<th>20-gauge</th>
<th>23-gauge</th>
<th>25-gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. cutting rate (cpm)</td>
<td>2,500</td>
<td>2,500</td>
<td>1,500</td>
</tr>
<tr>
<td>Inherent stability (g/4 mm)</td>
<td>130</td>
<td>35</td>
<td>14</td>
</tr>
<tr>
<td>Flow rates (ml min⁻¹) at given vacuum levels and zero cuts</td>
<td>18 (150 mmHg)</td>
<td>23 (600 mmHg)</td>
<td>10 (600 mmHg)</td>
</tr>
<tr>
<td>Flow rates (ml min⁻¹) at given vacuum levels and max. cutting rate</td>
<td>9 (150 mmHg)</td>
<td>9 (600 mmHg)</td>
<td>5 (600 mmHg)</td>
</tr>
</tbody>
</table>

When working with the 23-gauge and 25-gauge systems, high suction levels are required to obtain sufficient flow rates. However, flow rates with the 25-gauge systems continue to remain distinctly lower (even at high suction levels) than those of the two other systems.
References

Core Message

- 25-gauge instrumentation has reduced the surgical incision size. This reduction in size has made vitreoretinal procedures not only sutureless but, more importantly, made the procedures less invasive and potentially safer.
- The sutureless 25-gauge pars plana vitrectomy reduces the postoperative inflammation at sclerotomy sites, thus reducing patient discomfort after surgery and hastening postoperative recovery.
- The majority of experienced vitreoretinal surgeons have now been exposed at some level to 25-gauge instrumentation, and many use it on a routine basis. However, only a few surgeons have experience with the engineering development challenges and trade-offs associated with small-diameter instrumentation.
- This chapter will explore some of the key areas of the design and functioning of small-diameter instruments, so that surgeons may better understand their performance.

2.1 Introduction

25-gauge instrumentation refers to the body of devices designed specifically to work in conjunction with the 25-gauge Entry Site Alignment system (ESA) or microcannula system. The ESA system is the key to 25-gauge instrumentation, and allows the surgeon pars plana access to the vitreous chamber without having to perform conjunctival peritomy (i.e., transconjunctival access), and the ability to remove the system without the need for sutures [1]. The main components used with the ESA system include: a fiber optic light pipe, vitreous cutter, and a range of manipulation and task-specific instruments (Fig. 2.1).

The main advantage of 25-gauge instrumentation — and that which creates engineering challenges — is the dimensional constraint of instruments 0.5 mm in diameter. Compared to 20-gauge, 25-gauge instruments have 70% less cross-sectional area to recreate the functionality surgeons expect (Fig. 2.2). This chapter will explore how the size of 25-gauge instrumentation affects mechanical properties, such as fluid dynamics and stiffness, and optical properties associated with illumination. As engineering solutions to these challenges continue to be developed, transconjunctival 25-gauge instrumentation will continue to improve as well.

Currently, there are at least four major brands of 25-gauge instrumentation Bausch and Lomb Inc. (St. Louis, MO, USA), Alcon Laboratories, Inc (Fort Worth, TX, USA), Dutch Ophthalmic, USA (Kingston, NH, USA), Synergetics Inc. (O’Fallon, MO, USA), as well as others) (Fig. 2.3). There are differences between these systems that affect their performance, and some of these will be highlighted. But, as designs evolve and new instrumentation is launched, the comparative landscape is constantly in flux. The goal of this chapter is to provide information on how the design parameters of 25-gauge instruments affect their performance, so that surgeons are better prepared to evaluate and operate current and future instrumentation. For example, 23-gauge instrumentation systems for use with tunneling scleral incisions are just beginning to be evaluated and compared to 20 and 25-gauge instrumentation [9]. Journal articles, conference presentations, and manufacturer information highlighting various comparisons may lead to confusion. Hopefully, this chapter will allow a better understanding of the underlying scientific reasons behind any performance differences.

2.2 Microcannula System

The 25-gauge Entry Site Alignment system (ESA) is the primary component of 25-gauge instrumentation. The ESA system establishes the pars plana transconjunctival