Thoracic surgery in children and adolescents is no longer the same as 20 years ago. Antenatal detection of structural abnormalities has preponed diagnostic and therapeutic procedures and surgical as well as interventional techniques have undergone considerable development. Furthermore, substantial progress has been made in practitioners’ general understanding of congenital thoracic malformations, in minimally invasive approaches to the thoracic cavity and surgery of the chest wall.

Today, neonatologists, pediatric pulmonologists and pediatric as well as thoracic surgeons are involved in the treatment of patients with thoracic problems, while imaging and anaesthesiological techniques remain particularly challenging in small and premature infants. However, correction of chest wall deformities is no longer recommended before puberty and transition of those patients has become a reality. As a consequence, the diagnosis and treatment of thoracic disorders are crossing borders and interdisciplinary cooperation has become mandatory.

Taking this evolution into account, the time for an innovative textbook of thoracic surgery for the first two decades of life has arisen. The idea behind this book is new: address to on experts and newcomers profit from an interactive concept.

We are very thankful that numerous well-known specialists have contributed to this book, be it through introducing topics, presenting their individual views or discussing some of the more controversial aspects related to this field. Recommended papers for further reading are included, and supplementary material can be found on the publisher’s website. In addition to presenting the work, ideas and research of experts, this textbook opens the door for an interactive exchange between author and reader.

Claus Petersen
Benno M. Ure
Contents

Prolog — v
Authors and contributors — xiii

1 Anesthesia and analgesia for thoracic surgery — 1
  1.1 Introduction — 1
  1.2 Anesthesia for pediatric thoracic surgery — 1
    1.2.1 Neurotoxicity of anesthesia in neonates, infants and young children — 1
    1.2.2 Basic anesthetic techniques in pediatric anesthesia — 2
    1.2.3 Age at and timing of surgery — 3
    1.2.4 Preoperative evaluation and workup — 4
    1.2.5 Intraoperative monitoring — 4
    1.2.6 Lung isolation and one lung ventilation in children — 5
    1.2.7 Anesthetic implications for specific disorders — 13
  1.3 Perioperative pain management — 24
    1.3.1 Systemic analgesia — 25
    1.3.2 Local-regional anesthesia — 27
  1.4 Further reading — 29

2 Approaches to the thoracic cavity — 31
  2.1 Introduction — 31
  2.2 Thoracotomy — 31
    2.2.1 Anterior thoracotomy — 31
    2.2.2 Posterolateral thoracotomy — 32
    2.2.3 Lateral muscle sparing thoracotomy (anterolateral/anteroaxillary thoracotomy) — 33
    2.2.4 Closure of the thoracotomy with regard to postoperative pain — 34
  2.3 Sternotomy — 37
    2.3.1 Median sternotomy — 37
    2.3.2 Partial median sternotomy (hemisternotomy, upper sternotomy) — 39
    2.3.3 Closure of the sternotomy — 40
    2.3.4 Extended approaches — 40
  2.4 Video-assisted thoracoscopic surgery (VATS): Development of the operative technique — 41
    2.4.1 Introduction — 41
    2.4.2 Ventilatory and pathophysiological considerations for VATS — 42
    2.4.3 Equipment — 43
    2.4.4 Positioning of the patient and trocar introduction — 45
    2.4.5 Indications, pros and cons for pediatric VATS — 48
  2.5 Bronchoscopy — 51
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5.1</td>
<td>Introduction</td>
<td>51</td>
</tr>
<tr>
<td>2.5.2</td>
<td>Bronchoscopes</td>
<td>51</td>
</tr>
<tr>
<td>2.5.3</td>
<td>Sedation and anesthesia</td>
<td>52</td>
</tr>
<tr>
<td>2.5.4</td>
<td>Diagnostic procedures</td>
<td>52</td>
</tr>
<tr>
<td>2.6</td>
<td>Further reading</td>
<td>65</td>
</tr>
<tr>
<td>3</td>
<td>Bronchopulmonary diseases</td>
<td>68</td>
</tr>
<tr>
<td>3.1</td>
<td>Introduction</td>
<td>68</td>
</tr>
<tr>
<td>3.2</td>
<td>Congenital thoracic malformations</td>
<td>68</td>
</tr>
<tr>
<td>3.2.1</td>
<td>Congenital cystic adenomatoid malformation (CCAM)</td>
<td>69</td>
</tr>
<tr>
<td>3.2.2</td>
<td>Sequestration</td>
<td>72</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Congenital lobar and segmental emphysema</td>
<td>75</td>
</tr>
<tr>
<td>3.2.4</td>
<td>Bronchogenic and foregut duplication cysts</td>
<td>77</td>
</tr>
<tr>
<td>3.2.5</td>
<td>VATS in congenital thoracic malformations</td>
<td>79</td>
</tr>
<tr>
<td>3.3</td>
<td>Airway diseases</td>
<td>86</td>
</tr>
<tr>
<td>3.3.1</td>
<td>Introduction</td>
<td>86</td>
</tr>
<tr>
<td>3.3.2</td>
<td>Laryngotracheal reconstruction</td>
<td>87</td>
</tr>
<tr>
<td>3.3.3</td>
<td>Tracheostomy</td>
<td>93</td>
</tr>
<tr>
<td>3.4</td>
<td>Further reading</td>
<td>112</td>
</tr>
<tr>
<td>4</td>
<td>Lung transplantation</td>
<td>117</td>
</tr>
<tr>
<td>4.1</td>
<td>Introduction</td>
<td>117</td>
</tr>
<tr>
<td>4.2</td>
<td>General considerations</td>
<td>117</td>
</tr>
<tr>
<td>4.3</td>
<td>Indications</td>
<td>117</td>
</tr>
<tr>
<td>4.4</td>
<td>Allocation and size matching</td>
<td>119</td>
</tr>
<tr>
<td>4.5</td>
<td>Surgical technique and lobar transplantation</td>
<td>119</td>
</tr>
<tr>
<td>4.6</td>
<td>Living donation</td>
<td>121</td>
</tr>
<tr>
<td>4.7</td>
<td>Extracorporeal support</td>
<td>122</td>
</tr>
<tr>
<td>4.8</td>
<td>Outcome</td>
<td>123</td>
</tr>
<tr>
<td>4.9</td>
<td>Retransplantation</td>
<td>124</td>
</tr>
<tr>
<td>4.10</td>
<td>Summary</td>
<td>125</td>
</tr>
<tr>
<td>4.11</td>
<td>Further reading</td>
<td>126</td>
</tr>
<tr>
<td>5</td>
<td>Tumors in childhood and adolescence</td>
<td>128</td>
</tr>
<tr>
<td>5.1</td>
<td>Introduction</td>
<td>128</td>
</tr>
<tr>
<td>5.2</td>
<td>Primary lung tumors in childhood and adolescence</td>
<td>128</td>
</tr>
<tr>
<td>5.2.1</td>
<td>General considerations</td>
<td>128</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Bronchial carcinoid tumor</td>
<td>129</td>
</tr>
<tr>
<td>5.2.3</td>
<td>Mucopidermoid carcinoma of the bronchus</td>
<td>132</td>
</tr>
<tr>
<td>5.2.4</td>
<td>Adenoid cystic carcinoma</td>
<td>134</td>
</tr>
<tr>
<td>5.2.5</td>
<td>Pulmonary blastoma</td>
<td>134</td>
</tr>
<tr>
<td>5.2.6</td>
<td>Bronchioloalveolar carcinoma/adenocarcinoma in situ</td>
<td>136</td>
</tr>
<tr>
<td>5.2.7</td>
<td>Hemangiopericytoma</td>
<td>137</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>5.2.8</td>
<td>Inflammatory myofibroblastic tumors — 138</td>
<td></td>
</tr>
<tr>
<td>5.2.9</td>
<td>Pulmonary arteriovenous malformations — 140</td>
<td></td>
</tr>
<tr>
<td>5.2.10</td>
<td>Hamartoma — 141</td>
<td></td>
</tr>
<tr>
<td>5.2.11</td>
<td>Juvenile respiratory papillomatosis — 141</td>
<td></td>
</tr>
<tr>
<td>5.3</td>
<td>Chest wall tumors in childhood and adolescence — 142</td>
<td></td>
</tr>
<tr>
<td>5.3.1</td>
<td>General considerations — 142</td>
<td></td>
</tr>
<tr>
<td>5.3.2</td>
<td>Primitive neuroectodermal tumors (PNETs) — 143</td>
<td></td>
</tr>
<tr>
<td>5.3.3</td>
<td>Rhabdomyosarcoma — 144</td>
<td></td>
</tr>
<tr>
<td>5.3.4</td>
<td>Osteosarcoma/malignant fibrohistiocytoma — 146</td>
<td></td>
</tr>
<tr>
<td>5.3.5</td>
<td>Fibrosarcoma — 146</td>
<td></td>
</tr>
<tr>
<td>5.3.6</td>
<td>Hemangiopericytoma — 147</td>
<td></td>
</tr>
<tr>
<td>5.3.7</td>
<td>Langerhans cell histiocytosis (LCH) — 147</td>
<td></td>
</tr>
<tr>
<td>5.3.8</td>
<td>Lipoblastoma — 148</td>
<td></td>
</tr>
<tr>
<td>5.3.9</td>
<td>Mesenchymal hamartoma — 148</td>
<td></td>
</tr>
<tr>
<td>5.3.10</td>
<td>Chondroma — 149</td>
<td></td>
</tr>
<tr>
<td>5.3.11</td>
<td>Desmoid tumor — 149</td>
<td></td>
</tr>
<tr>
<td>5.4</td>
<td>Primary mediastinal tumors in childhood and adolescence — 149</td>
<td></td>
</tr>
<tr>
<td>5.4.1</td>
<td>General considerations — 149</td>
<td></td>
</tr>
<tr>
<td>5.4.2</td>
<td>Lymphoma — 150</td>
<td></td>
</tr>
<tr>
<td>5.4.3</td>
<td>Extragonadal germ cell tumors — 151</td>
<td></td>
</tr>
<tr>
<td>5.4.4</td>
<td>Thymoma and thymic carcinoma — 153</td>
<td></td>
</tr>
<tr>
<td>5.4.5</td>
<td>Neurogenic tumors — 154</td>
<td></td>
</tr>
<tr>
<td>5.5</td>
<td>Further reading — 157</td>
<td></td>
</tr>
</tbody>
</table>

### 6 Diaphragm — 161

6.1 Introduction — 161

6.2 Congenital diaphragmatic hernia (CDH) — 161

6.2.1 Introduction — 161

6.2.2 Epidemiology of CDH — 162

6.2.3 Pathophysiology of CDH — 162

6.2.4 Prenatal diagnosis — 162

6.2.5 Treatment — 163

6.2.6 Surgical therapy — 164

6.2.7 Long-term follow-up — 168

6.2.8 Implications and future perspectives — 171

6.3 Eventration — 172

6.3.1 Introduction – definition — 172

6.3.2 Etiology, physiopathology — 172

6.3.3 Clinical presentation — 172

6.3.4 Paraclinical investigation — 173

6.3.5 Treatment — 173
6.3.6 Follow-up — 179
6.4 Further reading — 179

7 Thoracic wall — 183
7.1 Introduction — 183
7.2 Pectus excavatum — 183
7.2.1 Indication — 184
7.2.2 Preoperative evaluation — 185
7.2.3 Technique — 185
7.2.4 Postoperative care and follow up — 189
7.2.5 Complications — 190
7.2.6 Removal of the bar(s) — 190
7.3 Pectus carinatum — 198
7.4 Miscellaneous — 205
7.4.1 Poland syndrome — 205
7.4.2 Jeune syndrome — 205
7.4.3 Sternal defects — 206
7.4.4 Defects of the thoracic wall — 206
7.5 Trauma — 208
7.5.1 Introduction — 208
7.5.2 Biomechanics and anatomy — 209
7.5.3 General evaluation and initial management of the child with chest injuries — 209
7.5.4 Airway obstruction — 211
7.5.5 Traumatic asphyxia — 211
7.5.6 Chest wall injuries — 212
7.5.7 Pulmonary injuries — 215
7.5.8 Tracheobronchial injuries — 220
7.5.9 Esophageal injuries — 221
7.5.10 Diaphragmatic injuries — 222
7.5.11 Great vessel injuries — 224
7.5.12 Heart and pericardium — 224
7.5.13 Resuscitative thoracotomy — 226
7.5.14 Pitfalls in pediatric thoracic trauma — 227
7.5.15 Conclusion — 227
7.6 Further reading — 228

8 Miscellaneous infection — 234
8.1 Introduction — 234
8.2 Empyema (including lung abcess) — 234
8.3 Echinococcosis — 241
8.3.1 Introduction — 241
8.3.2  Cystic echinococcosis — 241
8.3.3  Alveolar echinococcosis — 252
8.4  Chylothorax in neonates — 255
8.5  Acquired chylothorax — 257
8.6  Thymus — 260
8.7  Hyperhidrosis — 264
8.7.1  Introduction — 264
8.7.2  Clinical management — 265
8.7.3  Surgical treatment — 269
8.7.4  Conclusions — 273
8.8  Further reading — 275

Index — 281
Authors and contributors

**Anesthesia and Analgesia for Thoracic Surgery**

- Christian Seefelder
  Department of Anesthesiology, Perioperative and Pain Medicine, Boston Children’s Hospital, Boston, MA, USA
  Christian.Seefelder@childrens.harvard.edu

**Approaches to the Thoracic Cavity**

- Marcus Krüger, Taufiek Konrad Rajab
  Department of Cardiothoracic, Transplantation and Vascular Surgery, Hannover Medical School, Hannover, Germany; Department of Surgery, Brigham and Women’s Hospital and Harvard Medical School, Boston, USA
  Marcus.Krueger@Martha-Maria.de, trajab@rics.bwh.harvard.edu

- Jens Dingemann, Benno M. Ure
  Department of Pediatric Surgery, Hannover Medical School, Hannover, Germany
  ure.benno@mh-hannover.de, Dingemann.Jens@mh-hannover.de

- Nicolaus Schwerk
  Department of Pediatric Pneumology, Allergology and Neonatology, Hannover Medical School, Hannover, Germany
  schwerk.nicolaus@mh-hannover.de

- Rolf Oerter
  Department of Thoracic Surgery, University Rostock, Germany
  rolf.oerter@med.uni-rostock.de

- Hartmut Grasemann
  Division of Respiratory Medicien, Department of Paediatrics, The Hospital for Sick Children, Toronto, Canada
  hartmut.grasemann@sickkids.ca

- Pierre Goussard
  Department of Pediatrics and ChildHealth, Stellenbosch University, Tygerberg Children’s Hospital, Cape Town, South Africa
  pgouss@sun.ac.za

- Steve Cunningham
  Dept. of Respiratory & Sleep Medicine, Royal Hospital for Sick Children, Edinburgh, UK
  steve.cunningham@nhs.net

- Jacques de Blic
  Service Pneumologie et Allergologie Pédiatriques, Hôpital Universitaire Necker Enfants Malades, Paris, France
  j.deblic@aphp.fr

**Bronchopulmonary Diseases**

- Ernst Eber
  Division of Paediatric Pulmonology and Allergology, Department of Paediatrics and Adolescent Medicine, Medical University of Graz, Austria
  ernst.eber@medunigraz.at

- Steven Rothenberg
  Department of Pediatric Surgery and Pediatrics, Rocky Mountain Hospital for Children in Denver, USA
  steverberg@aol.com

- Mark Davenport
  Department of Pediatric Surgery, King’s College Hospital, London, UK
  markdav2@ntlworld.com

- Konrad Hoetzenecker, Walter Klepetko
  Department of Thoracic Surgery, Medical University Vienna, Austria
  walter.klepetko@meduniwien.ac.at, konrad.hoetzenecker@meduniwien.ac.at

- Martin Lacher, Oliver J. Muensterer
  Department of Pediatric Surgery, University of Leipzig, Germany; Department of Pediatric Surgery, University Medicine of the Johannes Gutenberg University Mainz, Germany
  martin.lacher@uniklinik-leipzig.de, oliver.muensterer@unimedizin-mainz.de
Lung Transplantation
Clemens Aigner, Walter Klepetko
Department of Thoracic Surgery, Medical University Essen, Germany; Department of Thoracic Surgery, Medical University Vienna, Austria
clemens.aigner@rlk.uk-essen.de, walter.klepetko@meduniwien.ac.at

Axel Haverich
Department of Cardiac, Thoracic, Transplantation and Vascular Surgery, Hannover Medical School, Hannover, Germany
Haverich.Axel@mh-hannover.de

Tumors
Jochen Hubertus, Dietrich von Schweinitz
Department of Pediatric Surgery, Dr. von Haunersches Kinderspital, Munich, Germany
Jochen.Hubertus@med.uni-muenchen.de, Dietrich.Schweinitz@med.uni-muenchen.de

Diaphragm
Dick Tibboel, René Wijnen, Hanneke IJsselstijn
Intensive Care and Department of Pediatric Surgery, Erasmus MC – Sophia Children’s Hospital, Rotterdam, The Netherlands
d.tibboel@erasmusmc.nl, r.wijnen@erasmusmc.nl

Anne Schneider, Francesca Borruto, Francois Becmeur
Department of Pediatric Surgery, University Hospital Strasbourg, Strasbourg, France
Francois.Becmeur@chru-strasbourg.fr

Thoracic Wall
Hans Pilegaard
Department of Cardiothoracic and Vascular Surgery, Aarhus University Hospital, Denmark
pilegaard@dadlnet.dk

Caroline Fortmann, Claus Petersen
Department of Pediatric Surgery, Hannover Medical School, Hannover, Germany
fortmann.caroline@mh-hannover.de, petersen.claus@mh-hannover.de

Haiko K Jahn, Sebastian van As
Trauma Unit Red Cross Children’s Hospital, Cape Town, South Africa
Sebastian.vanas@uct.ac.za

Frederic Lavrand
Department of Pediatric Surgery, Pellegrin-Enfant Hospital, Bordeaux, France
frederic.lavrand@chu-bordeaux.fr

Hyung Joo Park
Department of Thoracic and Cardiovascular Surgery, Seoul St. Mary’s Hospital, Seoul, South Korea
hyjpark@catholic.ac.kr

Donald Nuss
Childrens’ Hospital of The King’s Daughters, Eastern Virginia Medical School, Norfolk, Virginia, USA
dnuss@umd.edu

Claus Petersen
Department of Pediatric Surgery, Hannover Medical School, Hannover, Germany
petersen.claus@mh-hannover.de

Horatio Abramson
Hospital del Tórax Antonio A. Cetrángolo, Universidad de Buenos Aires, Argentina
habramson@intramed.net.ar

Francis Robicsek
Department of Thoracic and Cardiovascular Surgery, University of North Carolina, Charlotte, USA
Francis.Robicsek@carolinashealthcare.org

Marcelo Martínez Ferro
Division Department of Surgery, Fundación Hospitalaria Children’s Hospital, Ciudad Autónoma de Buenos Aires, Argentina
m.martinezferro@gmail.com

Robert E. Kelly
Childrens’ Hospital of The King’s Daughters, Eastern Virginia Medical School, Norfolk, Virginia, USA
Robert.Kelly@chkd.org

Jean-Marie Wihlm
Department of Thoracic Surgery, University Hospital Cochin, Paris, France
jmwihlm@gmail.com

Dawn E. Jaroszewski
Cardiothoracic Surgery, Mayo Clinic, Arizona, USA
Jaroszewski.Dawn@mayo.edu
**Miscellaneous Infections**

Juan Tovar  
Emeritus Professor, Department of Pediatric Surgery, Hospital Universitario La Paz, Madrid, Spain  
juan.tovar@salud.madrid.org

Akin Kuzucu  
Department of Thoracic Surgery, Turgut Ozal Medical Center, Inonu University School of Medicine, Malatya, Turkey  
akin.kuzucu@inonu.edu.tr

Thomas Junghans  
Section Clinical Tropical Medicine Department Infectious Diseases, University Hospital Heidelberg, Germany  
thomas.junghanss@urz.uni-heidelberg.de

Marija Stojkovic  
Section Clinical Tropical Medicine Department Infectious Diseases, University Hospital Heidelberg, Germany  
marija.stojkovic@med.uni-heidelberg.de

Anja Bialkowski, Christian Poets  
Department of Neonatology, Tuebingen University Hospital, Tuebingen, Germany  
anja.bialkowski@gmx.de, christian-f.poets@med.uni-tuebingen.de

Bethany J. Slater, Steven S. Rothenberg  
Rocky Mountain Pediatric Surgery, Denver, Colorado, USA  
bjslater1@gmail.com, steverberg@aol.com

Hanmin Lee, Lan Vu  
Fetal treatment center, San Francisco, USA  
hanmin.Lee@ucsf.edu, lan.vu@ucsf.edu

Jose Ribas Milanez de Campos  
Department of thoracic and Pediatric Surgery, University of Sao Paulo, Brazil  
jribas@usp.br

Marcus Krüger  
Department of Cardiothoracic, Transplantation and Vascular Surgery, Hannover Medical School, Hannover, Germany  
Krueger.Marcus@mh-hannover.de