SEE++ User Manual

Revision 11

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Target Audience

This user manual is an introduction to the computer-aided simulation system SEE++ which can be used for the simulation of eye motility disorders and for the preparation and simulation of eye muscle surgeries.

This manual addresses ophthalmologists, orthoptics, pediatrists, neurologists, specialists as well as laymen who are interested in the areas of mathematics, physics and computer science and who are familiar with medical topics.

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Michael Buchberger, Thomas Kaltofen, Siegfried Priglinger

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1 Introduction

1.1 Preface

Increasing automation within all areas in everyday life make the application of software systems for administration and services essential. For the past few years, this development has been strongly supported by the Austrian health-care system. The implementation of a chip card system instead of health insurance certificates and the numerous innovations in the IT-supported hospital administration form the base for an efficient and cost-minimizing administration in health-care.

The rapid development of computer systems increasingly allows the application of software systems within the medical field. Even today high-capacity computers for image processing and 3D graphics in combination with specialized systems provide a reasonable addition e.g. in medical diagnosis. A basic criterion for the use of such systems in practice is their reliability and an authentic representation of medical data and results respectively, which eliminates errors in interpretation as good as possible. In the application of virtual reality in connection with surgical interventions, the success of an operation is substantially influenced by data obtained from such a system. Detailed graphical visualization enables the surgeon to preoperatively simulate a disease and afterwards, by means of interactive "virtual surgery", plan, check and possibly even correct a surgical procedure in order to achieve the best result.

Due to the constantly rising demand of such systems, substantial research in surrounding fields of computer sciences are concerned with the "correct" modeling of a "virtual" human. The goal of this work is to represent the anatomy of the human body as realistically as possible by trying to apply well-known relationships from the mechanics to the anatomy of humans. Complex mathematical models of skeletons, muscles, joints and their graphical, three-dimensional visualization form the basis of an interactive system. The result is a biomechanical model of the human body, which again, finds application in research and study. By systematic studying of such systems, new insight can be derived, integrated into the model and subsequently be used to extend research.

The SEE-KID (Software Engineering Environment for Knowledge-based Interactive Eye motility Diagnostics) project tries to connect aspects of biomechanical modeling with methods of modern software engineering. This project is mainly based upon the Orbit™ software system (see www.eidactics.com) and other biomechanical software, however, it tries to extend functionality and supply different modeling aspects within one single computer application.

We see SEE++ as replacement or extension to Orbit™ with more clinical relevance while providing essential functionality similar to what Orbit™ offered. The SEE++ software differentiates between biomechanical models and user interfaces and therefore provides an open, flexible and portable basis for further development. Additionally, the "SEE-KID" and "SEE-KID Active Pulley" models have been developed in order to incorporate new anatomic and physiological findings from basic research. Compared to Orbit™, these models also use a different mathematical approach for numerical optimization in order to more reliably solve non-linear problems, a special and important task when simulating the statics of mechanical systems like the human eye.

The department of ophthalmology at the convent hospital of the "Barmherzigen Brüder" in Linz, Austria, is the direct partner of the SEE-KID project and has specialized in correcting congenital and acquired eye motility disorders (e.g. strabismus with or without nystagmus), particularly in infants, by e.g. resection or transposition of certain eye muscles. Most of these extraocular muscle surgeries have to be carried out in pre-school age. To avoid a permanent misalignment and a sensory adaptation resulting from it, in individual cases (e.g. fibrosis syndrome) children have to be operated as soon as possible at an early age. Prerequisite for such surgeries is an early diagnosis including a pretreatment e.g. via occlusion (masking the better eye in order to support the weaker eye).

For the success of an extraocular eye muscle surgery it is not only important to understand the underlying mechanism of clinical findings, but also to understand the underlying anatomic functional mechanisms in order to avoid wrong or multiple surgical treatments.

Such model-supported eye muscle surgeries have been performed at the hospital of the "Barmherzigen Brüder" in Linz, Austria, since 1978. Thus it was also possible to develop new surgery techniques.

Especially complicated surgeries have to be planned in detail in the forefront of the actual intervention and appropriate surgery procedures have to be chosen. Up to now it has only been possible to carry out and perfect the process of a surgery directly on the patient. In the case of particularly complicated pathologies, even the experienced surgeon has to rely on documented empirical values, which often leads to multiple treatments until the result is satisfying.

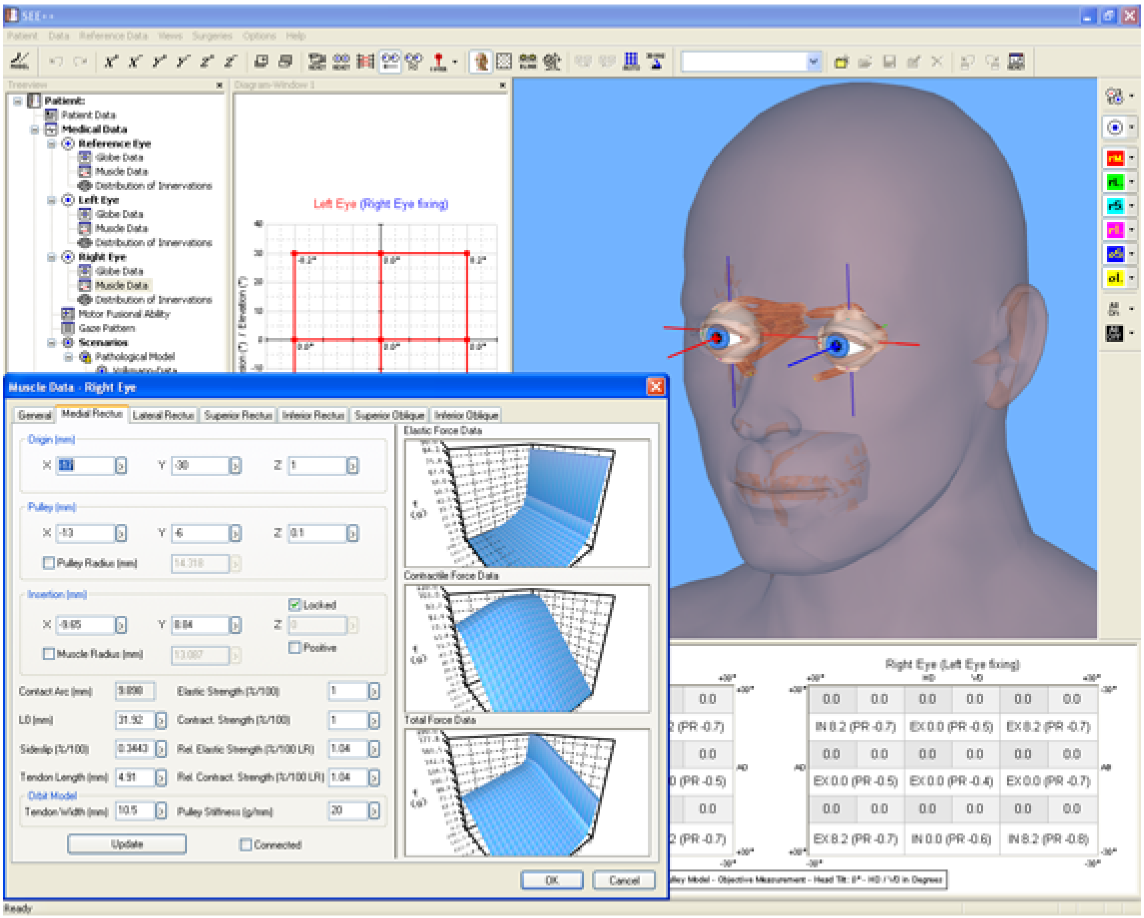
The result of our project is a software system (SEE++), which enables physicians to simulate eye motility disorders on the basis of patient measurements and to perform almost all possible surgical treatments interactively. Using a 3D representation of the geometry of the human eye as well as reference points, lever arm lines (the sum of all reference points with the same lever arm) and the relationship of origin and insertion on the surface of the eye or in the orbita ("Functional Topography") 33, the surgeon can model the disorders as deviations from a non-pathological "healthy" eye. Thus the surgeon can determine the optimal treatment for the patient and plan it in detail.

The simulated surgeries are visualized on the computer in a three-dimensional way and in diagrams for comparison with clinical measurements and they are checked for plausibility. In addition, reference points and measured values described above are displayed to the surgeon, enabling better orientation and correct positioning while operating a real patient's eye.

1.2 What is SEE++

SEE++ is a new simulation system for the prediction of clinical surgery results as well as for the illustration of pathological situations in the field of strabismus surgeries. The system is based on a highly developed mathematical simulation model (biomechanical model). It simulates the behaviour of the human eye together with the extraocular muscles in a realistic way and therefore provides an experimental platform for the simulation of pathologies and the evaluation of possible surgical treatments.

SEE++ is a biomechanical system for the interactive three-dimensional simulation and visualization of eye motility disorders and their surgical correction.



SEE++ offers:

- compact, descriptive and thus well understandable knowledge transfer in teaching and training,
- scientifically oriented procedures,
- exploration of basic principles supported by numerous examples,
- a basis for individual considerations of diagnostics and surgical correction of eye motility disorders.

SEE++ is suitable for many people:

- Ophthalmologists, specialists as well as orthoptists can use SEE++ to support measurements and to archive pathologies and treatment methods.
- Researchers in the field of ophthalmology, strabismology and neurology, pediatrists as well as researchers in the field of biophysics use SEE++ as an extensive scientific tool for the investigation of the mechanics of eye movements.
- SEE++ offers a substantial support to teachers through descriptive representation for understanding eye movements. Students have the possibility to interactively deepen their knowledge about (previously studied) fundamentals of eye movement and strabismus.

SEE++ is a Biomechanical Model

The interdisciplinary research area of biomechanical modeling deals with the computer-aided modeling of anatomical structures of the human body. The research project SEE-KID (Software Engineering Environment for Knowledge-based Interactive eye motility Diagnostics) presented here focuses on the virtual representation of the oculomotor apparatus in terms of a functional model of eye motility for the application in the field of ophthalmology.

Looking back on the history of the development of models in the field of strabismus, the strong mathematical implication and the multidisciplinary complexity of this subject area can be noticed. Especially in teaching and training in the field of ophthalmology a detailed understanding of the mechanics of eye movements as well as the functional connections of the anatomy of the oculomotor apparatus with regard to diagnosis and therapy of eye motility disorders is of major relevance. The computer-aided simulation system SEE++ presented here enables the doctor to simulate pathological situations with the computer, to visualize them graphically and interactively in a three-dimensional way as well as to calculate the effects of eye muscle surgeries in comparison to a selected standard model. Thus the surgeon can observe the trend of an eye muscle surgery already on the computer and determine the respective optimal treatment for a patient. By modeling and simulating eye motility disorders with the help of a model and by getting a deeper understanding of the underlying mechanism, multiple surgeries could be avoided.

Biomechanical modeling is defined as a subsection of mechanics. It deals with the effects of dynamical force relations of the human body. The basis for the implementation of such models is the combination of disciplines of physics with fields of biology and physiology. In the broadest sense, studying mechanical properties of the human body with the help of mathematical-physical methods can also be assigned to the new scientific discipline of bioinformatics.

Modeling of the oculomotor system is based on detailed knowledge of anatomical structures and was already described in first simple models in the 19th century. Volkmann was the first to perform extensive measurements of insertions and origins and to determine a detailed description of the geometry of extraocular muscles. Later, Krewson described the geometrical principles of ocular movements in a very simplified form by inventing the so-called "string model". Boeder transformed the mathematics of the string model into a graphically descriptive notation (muscle force distribution diagrams), which is still used in clinic and science today. The first model, which also considered movement-restraining structures of eye muscles, was published as "tape model" by Robinson in 1975. A mathematical reinforcement of this interpretation of muscle fixation led to the definition of the "intensified tape model" by Kusel and Haase in 1977. With the discovery of pulleys as functional elements, a new, advanced model of ocular motility called Orbit™ was introduced as the first commercially available biomechanical eye simulation by Joel Miller in 1994 (see [Miller 1999]), which, compared to older models and clinical data, supplied substantially more realistic predictions.

However, latest studies have shown that pulleys do not only determine and stabilize the muscle path, but that also the pulley position slightly changes with the gaze position. Thereby, the direction of pull of the eye muscles is affected, which can be seen by the bending of the muscle path in different gaze positions. Demer et. al. showed in a study that the pulley position moves backward when an eye muscle is contracted and forward during relaxation. This is called the "anterior – posterior shift" of pulleys. This so-called "Active-Pulley-Hypotheses" is also supported by other studies and was realized in the SEE++ system in form of the active pulley model. Consequently, SEE++ is the first simulation system that implements the "Active-Pulley-Hypotheses".

For the quality of a biomechanical model, characteristics of clinical results and dynamic expandability are of greatest importance. An existing model cannot be considered relevant unless the functional characteristics correspond tendentiously with clinical experiences. Furthermore, the model structure should be arranged in such a way that the incorporation of new physiological or biological findings will not invalidate the behavior of the current model formulation. In order to be able to realize such structures in a computer-aided model, additional methods of software engineering need to be applied.

1.3 Clinical Use

Due to the fact that this system has to be primary considered as **research support**, important restrictions for the clinical deployment have to be followed:

1. SEE++ **does not** serve as replacement for a clinical investigation or decision making process.
2. The software system SEE++ is **exclusively dedicated to supporting diagnosis and therapy** and may not **under any circumstances** be the sole basis for medical decision making.
3. SEE++ is **not primarily tested or certified for clinical use** and therefore **may not** be consulted as basis for the treatment of patients.

1.4 System Requirements

SEE++ runs on computers with a Windows® operating system installed.
Due to the graphically extensive representation and the computationally complex mathematical procedures used by SEE++, certain minimum requirements apply to a computer system running the software. These requirements should be fulfilled to guarantee a trouble-free operation of the software.

Requirements for SEE++:

- Operating system: Windows® 2000 or higher
- Intel Pentium 4 with 2 GHz minimum (or Intel Core architecture with 1.4 GHz minimum)
- 512 MB RAM minimum
- nVidia GeForce 4 with 64 MB RAM minimum or ATI Radeon 9000 with 64 MB RAM minimum
- Monitor or TFT display with a resolution of 1024x768 pixel minimum with True Color

1.5 Medical Foundations

1.5.1 Strabismus

Every permanent or regularly occurring misalignment of the eyes is described as squinting ("Strabismus"). Thereby the eyes are not parallel, but one eye diverges from the gaze direction of the other. About 6% of our population suffer from some form of strabismus. They suffer not only from the frequently disfiguring externally visible abnormality, the visual impairment associated with squint is an even greater burden. Squint is not just a blemish but often a severe visual impairment. The earlier squinting occurs in a child's life and the later it is treated by an ophthalmologist, the more serious the visual impairment will get. With the beginning of school age, the chances of success for the treatment significantly decrease. Squinting babies and infants therefore require a treatment as early as possible.

The Development of Visual Acuity

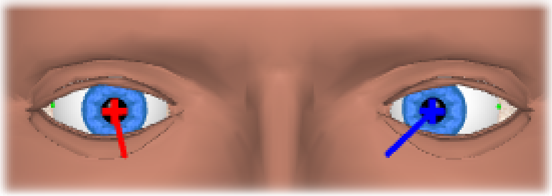
Babies are able to perceive their environment through their eyes quite soon after birth - but only indistinctly. In the first six months of life they learn to fixate with their eyes and to coordinate their eye movements. During this time of practice, occasional disorders of the eyes are still normal (so-called "baby squinting"). If, however, after the first sixth month of life one eye still deviates from the gaze direction of the other eye, an ophthalmologist should be consulted. In general, an examination of the eyes directly after birth would make sense to correct any disorders, e.g. a congenital cataract, at an early stage in the first weeks of life.

Visual acuity of infants improves continuously in the course of growth. By the time school age is reached, the eyes' learning program is virtually complete. The correction of amblyopia as a consequence of strabismus is only possible during this sensitive development phase. Already from the 7th-8th year of life the chances for a normalization of the visual acuity decrease seriously. After the 10th-12th year of life they are almost zero.

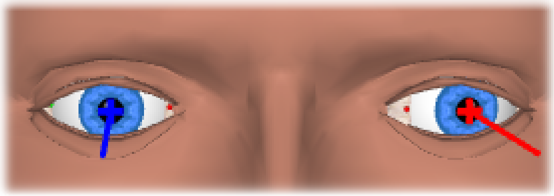
The Various Forms of Squinting

When squinting is present, one or sometimes both eyes deviate from their common gaze direction. If always the same eye is squinting because it has the poorer visual acuity or restricted movability, this is referred to as one-sided ("mono lateral") squinting. If, on the other hand, the deviation alternates between the right eye and the left eye, this is called alternating squinting. Occasionally, the deviation is so marginal (less than 5 degrees), that it is scarcely noticed. In this case one speaks of micro squinting, which normally is an inward squinting on one side and so marginal that parents do not recognize it or even think it looks cute. If a deviation in any direction can practically always be observed, it is referred to as manifest squinting. Occasionally, squinting can only be observed, if the binocular vision is restricted by covering one eye (Cover test) 50. In this case one speaks of a hidden ("latent") squinting, which is fully or partially compensated through an adequate fusional effort. This often leads to headache, reading problems etc. (asthenopic disorders). Squinting is never harmless or simply cute. It also "does not heal while growing up", but often causes amblyopia of one eye and serious disorders of the binocular and mainly of the high-quality three-dimensional vision, if the necessary ophthalmological treatment is delayed.

The squinting eye can deviate from the non-squinting eye in different directions: inwards (esophoria), outwards (exotropia), upwards (hyperphoria) or downwards (hypophoria). Sometimes a child suffers from deviations in different directions at the same time.



Inward Squint (Esophoria)



Outward Squint (Exotropia)

How Does Squinting Emerge ?

The causes of squinting are multifactorial. The fact that squinting occurs frequently in some families implies congenital factors. Particularly if one or both parents were squinting or were treated because of squinting, the child should have an ophthalmological examination right in the first year of life and every year later on. Further factors that can cause squinting and amblyopia are a pregnant mother's infection with rubella or premature birth. In most cases the causes can be found at the eye itself, such as a congenital refractive error (like hypermetropia or a serious corneal curvature) or a partial cataract, tumors inside the eye or injuries of the eye.

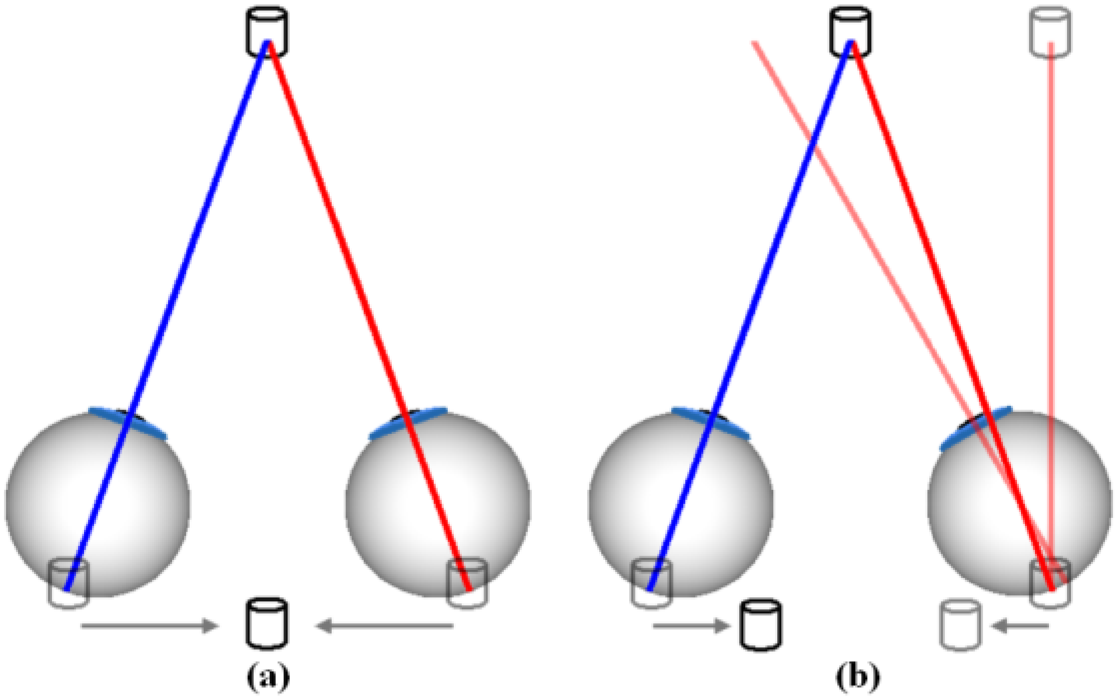
In case of congenital causes, the motility disorder isn't always obvious immediately after birth. In case of congenital refractive errors, squinting doesn't emerge until the child begins to fixate more accurately. In doing so the child often exclusively uses the functionally better eye, and so the more ametropic eye develops an amblyopia, if it isn't "trained" by therapeutic treatment. Sometimes an "acquired" disorder also suddenly appears, e.g. after children's diseases, after high fever, after accidents or in phases of serious psychological strain. Then latent strabismus is uncompensated due to an abnormal event.

Is There an Early Stage Indication for Squinting ?

Children with conspicuous strabismus have the best chances, because their parents will take them to the ophthalmologist early enough due to the "blemish". But unfortunately there also exist scarcely visible or invisible strabismus defects (micro strabismus). In case of latent strabismus, there are sometimes indications for decompensation due to manifest strabismus, e.g. occasional narrowing of one eye, sensitivity to light etc. A head posture is also common with nystagmus. But quite often children behave in an absolutely normal way and a visual impairment is first diagnosed in a serial examination in nursery, when one eye is already amblyopic and an effective treatment becomes difficult.

How Does Squinting Affect Vision ?

For three-dimensional spatial vision, both eyes must exactly fixate an object of interest. The image of this object is then projected onto the yellow spot (fovea), the center of sharpest vision, of both eyes. So, for example, a cube fixated with both eyes is projected upside down (like in a camera) and perspectively slightly different for each eye (due to the interpupillary distance of the eyes) onto the retina. In the brain, both images are merged in order to perceive one upright three-dimensional cube (fusion) (a).



This is different for an inward squinting of e.g. the right eye. According to this, the right eye fails to fixate the cube and misaligns as compared to the left eye (b). Different images are now projected onto the fovea of both eyes, and the brain fails to merge this information. The result is, that disturbing (uncrossed) double images are perceived. Especially in infants, the brain will compensate these errors by trying to eliminate those images that originate from the squinting eye. This process leads to a fatal outcome: the squinting eye will lose visual acuity and will suffer from amblyopia.

Amblyopia is referred to as a functional deficiency of visual acuity of an otherwise healthy eye, caused by e.g. squinting.
Without proper treatment, almost 90 % of all squinting children develop a one-sided amblyopia. The magnitude of the angle of squint is thereby negligible: especially in case of micro strabismus, amblyopia has a distinct tendency. If this amblyopia due to squinting is not discovered and treated early enough, it remains lifelong. Then the child can never learn how to see with both eyes or how to correctly see in a three-dimensional way. It is more at risk to get hurt in accidents and furthermore hindered in the freedom of choosing a career. A timely treatment can prevent an amblyopia due to squinting and can often establish limited binocular vision and also good three-dimensional spatial vision.

How Is Squinting Treated ?

The primary goal of treatment is to achieve the best possible binocular visual acuity (eyeglasses!). Only then a strabismus surgery with normal interaction of both eyes can be successful and enduring. Eyes without fixation (e.g. blind eyes) do not keep the parallel position after a strabismus surgery in most cases!

1) Eyeglasses

A not corrected ametropia can cause strabismus. Many children in Europe who suffer from strabismus are hyperopic. Excessive near fixation (accommodation) can result in squinting for these children due to the convergence impulse. Hyperopic eyeglasses, which are adjusted during a complete relaxation of accommodation by using eye drops, can therefore "heal" this type of accommodative strabismus or at least minimize the squint angle.

2) Covering ("Occlusion")

Occlusion of the normal eye is used to eliminate the amblyopia of the squinting eye. At the same time the eye muscle activity of the squinting eye is improved. A manifest squint angle cannot be corrected with this procedure, it can even increase.
According to the ophthalmologist's instructions, adhesive plasters are stuck over the normal and occasionally also over the squinting eye in a specific changing rhythm. This is done in order not to endanger the normal eye. If a child does not tolerate the plaster treatment, eye drops are prescribed. The eye drops widen the pupil of the normal eye and do not allow it to focus, especially in the near distance, anymore. Therefore, the child is forced to use the predominantly squinting, weaker eye and to "train" it that way (penalization).

If a certain visual acuity is reached, vision occlusion plasters are used. These are fixed onto the eyeglasses. The amblyopia treatment with such plasters often has to be discontinued "gradually" over years until adulthood in addition to eyeglasses and even after successful surgery.

3) Squint Surgery and Subsequent Treatment

The disorder of squinting children often has to be corrected through surgery of the outer eye muscles. Normally this is not done until the child has reached an approximately equal vision by the use of full-corrected eyeglasses. The strabismus surgery reduces or eliminates the squint angle. The postoperative wearing of glasses is still necessary. Furthermore, often an occlusion in terms of e.g. a part-time occlusion is necessary until adulthood.
Strabismus surgeries are normally low-risk surgeries and have good chances of success. They are performed on children in general anesthesia, that means that after a sedation, the "sedative injection" or the suppository and the initiation of the narcosis the child does not notice anything of the surgery.
The surgery is carried out by opening the conjunctiva in order to reach the extraocular muscles.
The operated eye is slightly reddened postoperatively. The child reduces the eye movements for approximately one day postoperatively. If a second surgery is necessary depends on the type of disorder and on the size of the squint angle.

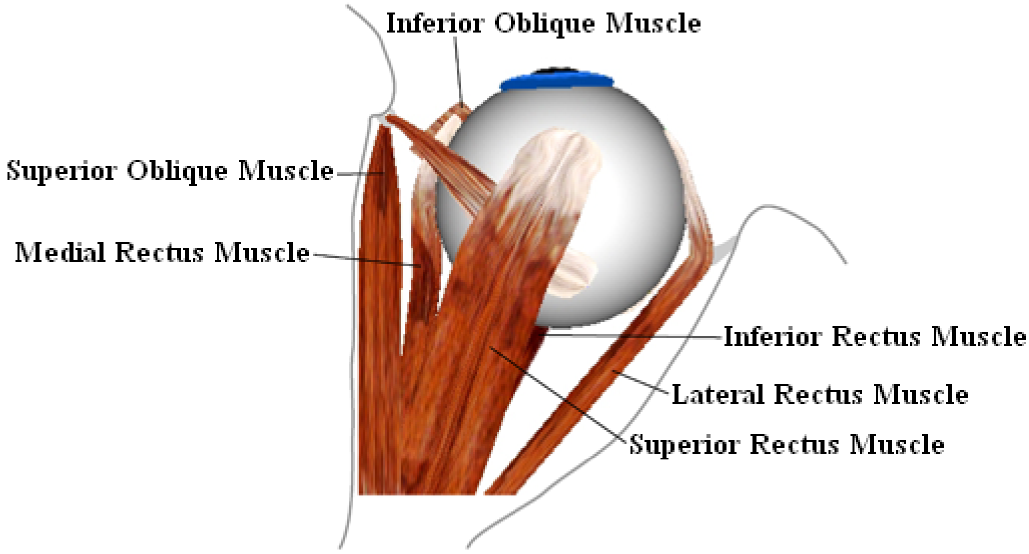
1.5.2 Anatomy of the Human Eye

The eyes, the "sense of visual perception", rank among the most important sensory organs of the human organism. They provide us with a constantly updated view of the environment. The following explanations refer to the right eye. The eyeball or globe (Latin bulbus oculi, briefly bulbus, ø approx. 24 mm, nearly spherical [Pschyrembel, 1994]) lies protected in the eye socket (orbita), that forms a cavity in the cranium. The globe is onion skin-like composed of three layers [Schäffler and Schmidt, 1998]:

- sclera (leather skin): outer eye skin,
- choroidea (vein skin): middle eye skin,
- retina: inner eye skin.

The six extraocular eye muscles are responsible for the movement of the globe. The four straight eye muscles (musculi recti) and the two oblique eye muscles (musculi obliqui) originate in the orbita and insert at the sclera of the globe. The figure shows the muscle origins in the orbita and their insertion on the globe. Each eye muscle affects the globe in three components, whereas the muscle path determines the main direction of pull. The main effect of each muscle can be derived from its name [Brugger, 2000].

- superior rectus muscle (upper straight eye muscle): upward,
- inferior rectus muscle (lower straight eye muscle): downward,
- lateral rectus muscle (outer straight eye muscle): sideways outward,
- medial rectus muscle (inner straight eye muscle): sideways inward,
- superior oblique muscle (upper oblique eye muscle): downward and incyclorotation,
- inferior oblique muscle (lower oblique eye muscle): upward and excyclorotation.

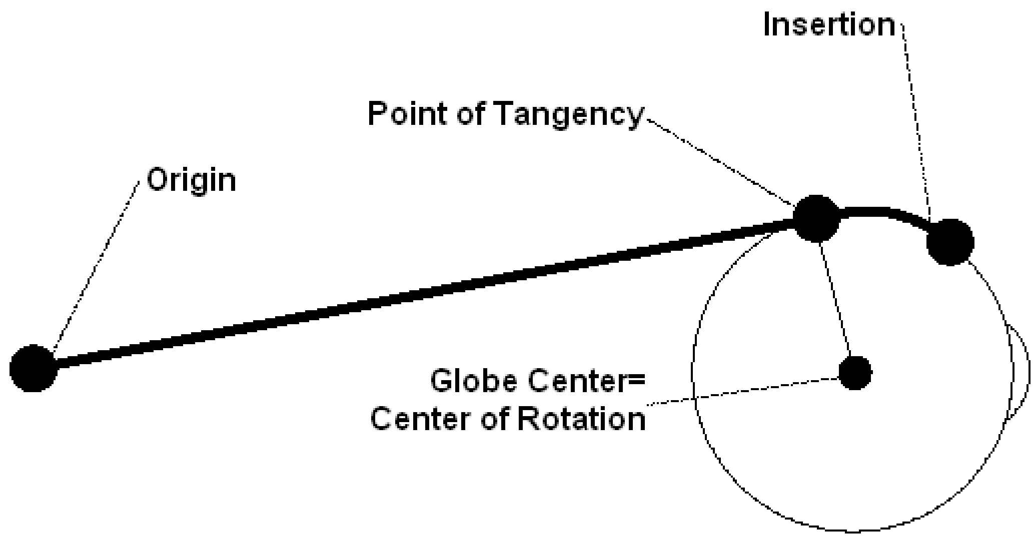


Top View of the Right Eye

The musculi recti originate at the posterior end of the orbita and are arranged in pairs right-angled to each other. Their end tendons join at the anatomic origin to a circular tendon plate (Zinn's ring) and their insertions lie before the equatorial plane of the globe (cf. [Günther, 1986]). In contrast, the musculi obliqui insert behind the globe equator and pull diagonally forward. The superior oblique muscle is the longest of all eye muscles. Starting from its origin near Zinn's ring it is running above the globe towards the nasal frontal bone, its tendon is slipping through a cartilaginous hole (the trochlea) and from there proceeds directly to its insertion. The inferior oblique muscle originates from the nasal edge of the bony orbita, runs below the globe around the inferior rectus muscle and inserts at the back area of the globe. In the area of intersection between inferior oblique muscle and inferior rectus muscle, both muscles are connected by the ligamentum lockwood [Günther, 1986].
Each eye muscle consists, apart from the purely muscular portion, also of a tendon which connects the muscle at the origin on one side and at the point of insertion on the other side. The overall length (muscle and tendon) of the extraocular muscles is very different. Thereby the lengths of the tendons show the largest differences (cf. [Kaufmann, 1995]). The inferior oblique muscle has the shortest tendon with 0 to 2 mm and the superior oblique muscle has the longest tendon with 25 to 32 mm. The actual muscle length (without the tendon) lies between 30 mm

(musculi obliqui) and 39 mm (inferior rectus muscle). Due to the insertion lying before or behind the equator of the globe, each muscle partially contacts the globe's surface. At the point of tangency, the muscle loses contact to the globe and pulls toward its origin (cf. Fig.). With each movement of the globe, the relative position of a muscle's insertion changes with respect to the orbita.

If the muscles could move freely between insertion and origin during an eye movement (hypothesis of the string model), a shift of the muscle path on the globe surface would occur, especially in tertiary gaze positions. Thereby the muscle path and consequently the direction of pull would change considerably according to the current eye position (loss of the main direction of pull). In order to avoid this, connective tissue surrounds the globe and stabilizes the muscles within the area of the point of tangency. These stabilizers are called pulleys (cf. [Buchberger and Mayr, 2000], [Miller and Demer, 1996]).



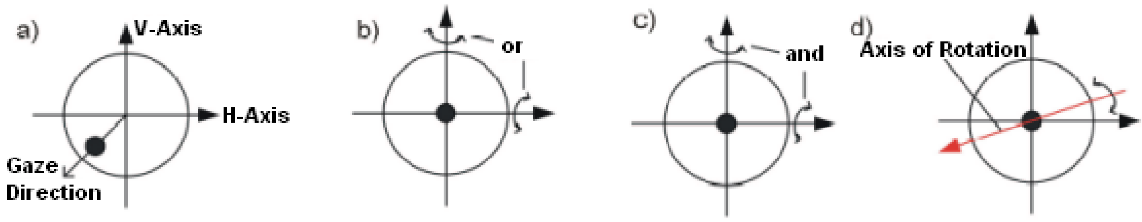
Schematic Illustration of a Straight Eye Muscle with Origin, Point of Tangency and Insertion

The movement of the globe approximately corresponds to a rotation of an object in the three-dimensional space around a certain axis. The globe center can be regarded as rotation center. The line of sight is a vector from the globe center through the center of the pupil. Perpendicular to this vector, the vertical and the horizontal axes are defined, whereas the intersection of these three axes lies in the globe center (cf. Fig.). Eye positions can be classified by their rotational properties (cf. [Kaufmann, 1995]):

- Primary position: The eye looks straightforward, with the head fixed and upright. It is assumed, that in this position all muscles exhibit minimum force (rest tonus). From this position all the other gaze positions can be reached with little energy demand.

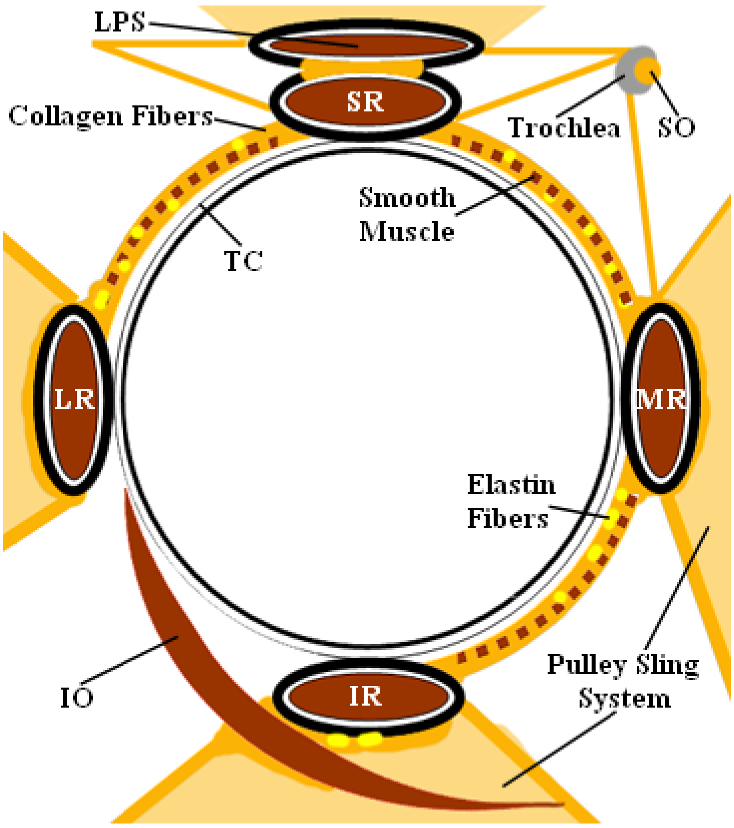
- Secondary position: Starting from the primary position, a rotation around the horizontal or vertical axis is performed (Fig. b). The eye looks to the left or to the right or respectively upwards or downwards.

- Tertiary position: Starting from the primary position, a rotation around the horizontal and vertical axis is performed (Fig. c). The eye looks e.g. to the left and up or to the right and down. The combination around two axes can also be represented by one single rotation axis, which lies in the plane spanned by the horizontal and vertical axis (Fig. d).



Line of Sight, Vertical and Horizontal Axis; Rotations to Other Eye Positions

Both eyes can only be moved together in binocular community, which means that the movement of only one eye is normally impossible (cf. [Günther, 1986]). Eye muscles are able to reposition the eye accurately and very fast, moreover, they can hold a certain position without exhaustion.
The rotation of an eye around a certain axis results in a certain gaze position and thus also realigns the line of sight to a new gaze direction. The gaze direction designates the orientation of the eye, whereas the gaze position should always come along with a fixation of the eye onto an object.
As mentioned before, each muscle is defined through its origin, point of tangency and insertion. The muscle paths from the origin to the insertion on the globe are, however, additionally influenced by connective tissue, the so-called "pulleys".
The following figure shows a schematic illustration of these anatomical structures:

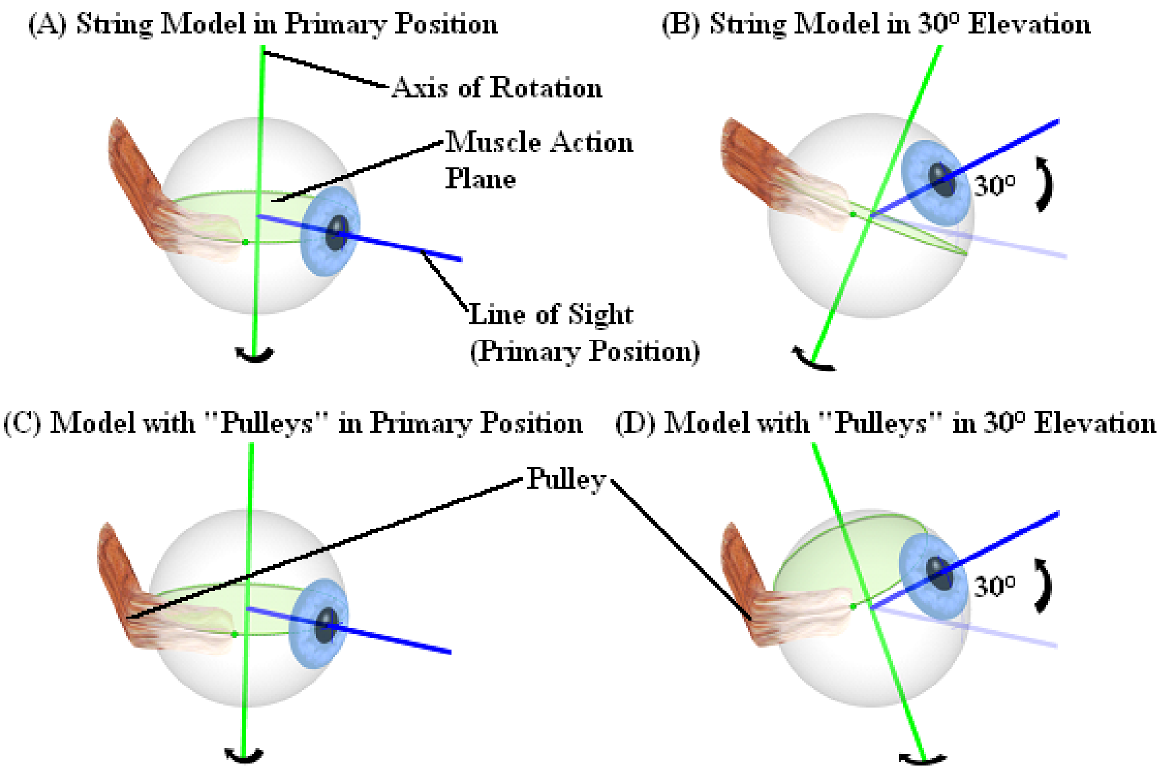


Representation of the Orbital Connective Tissue [Miller and Demer, 1999]

A "pulley" encloses a muscle as a circular structure and is connected with the orbital wall (retinacula) and other connective tissue structures (inter-muscular membrane). Smooth musculature and nerves are contained in this apparatus. Tendons and muscles travel through these pulleys, whereas the pulleys themselves are fixed relative to the orbita and are located near the bulbus equator in primary position

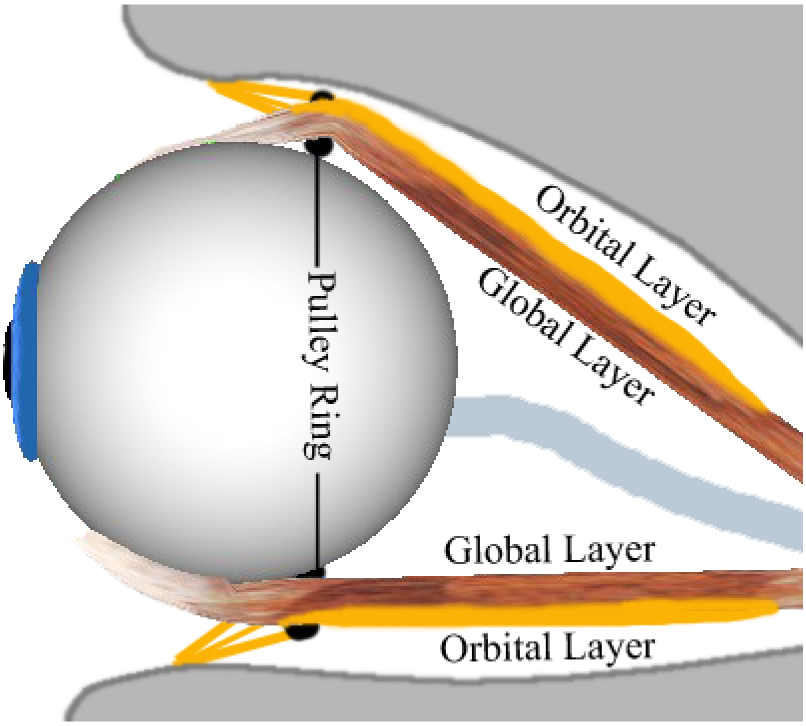
Anatomical Influence of Pulleys on Eye Movements

Before the discovery of pulleys as functional elements (1995) all models were based on the assumption that the anatomical origin of an eye muscle is also the functional origin. This again leads to the assumption, that the rotation axis, around which a muscle rotates the globe, is perpendicular to the plane defined by a muscle's point of tangency, center of rotation and anatomical origin. With the discovery of pulleys as functional elements, this definition of the axis of rotation is no longer valid. Therefore, according to the pulley model, the effective pulley location can be assumed as the actual functional origin of an extraocular eye muscle, since the muscle changes its main direction of pull at this position due to the presence of the pulley. As a consequence, the axis of rotation now has to be defined through a muscle's point of tangency, the center of rotation and a muscle's effective pulley location. The string model of Robinson (1975) as well as the so-called "intensified string model" according to Kusel and Haase (1977) have already tried to consider the influence of pulleys via a component which reduces the sideslip angle for each muscle. In contrast, there are newer models like Orbit™, Eyelab and SEE-KID, which already include pulleys as anatomical components and as a consequence also provide more accurate results compared to clinical data.



Difference Between Conventional Models (Above) and Models with Pulleys (Below)

The discovery of pulleys as functional elements explained, why all other models were less successful in comparison with real clinical data. Also the implementation of surgery simulations had to be adapted to these new findings.



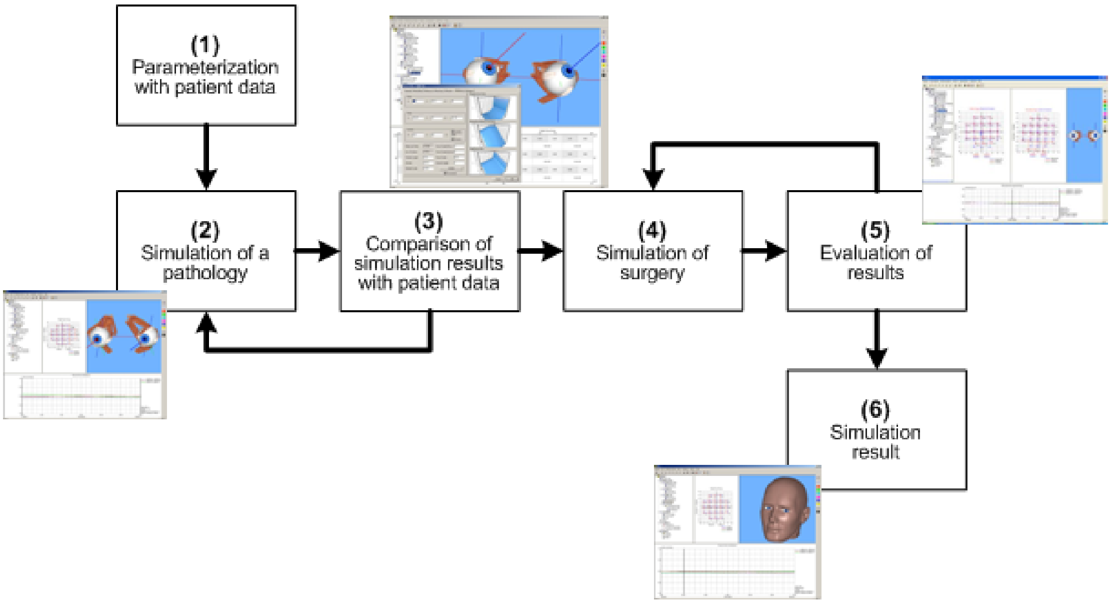
Global Layer and Orbital Layer of Superior Rectus Muscle and Inferior Rectus Muscle

Previous studies with mammals have already suggested that the extraocular eye muscles consist of two different layers. As shown in the preceding figure, the global layer runs continuously from the origin (near Zinn's ring) to the muscle's insertion on the globe. In contrast, the orbital layer ends slightly behind the insertion.

Several studies by [Demer et. al., 2000] and [Clark et. al., 2000] have shown, that each of these two layers has a different function. While the global layer is primarily responsible for the movement of the eye into a certain gaze position and runs up to the insertion, the orbital layer ends in the area of the pulleys and actively moves the pulleys when the eye is looking in a secondary or tertiary position. It could be shown by various studies, that the pulley position moves backwards during the contraction of an eye muscle and forwards during relaxation. These findings led to the formulation of the "Active-Pulley-Hypothesis", which is implemented in the SEE++ system in form of the active-pulley model. SEE++ is the first simulation system implementing the "Active-Pulley-Hypothesis".

1.6 Using SEE++

SEE++ is used in the following task flow:



1. Parameterization with Patient Data

The goal of SEE++ is to offer an as realistic as possible visualization of a patient specific situation. In this first step of a simulation sequence, the model is parameterized with values measured directly on the patient. In this process, parameters like globe radius, cornea, muscle lengths, insertions, tendons, etc. can be modified. At the same time, general data such as name or description are entered.

2. Simulation of a Pathology

During the simulation of a pathology, model parameters are changed in a way that the resulting model predictions correspond to patient measured values as close as possible. A model prediction is done in SEE++ by the simulation of a clinical Hess-Lancaster test, whereas the representations of right eye fixing and left eye fixing are used. By comparing the Hess-Lancaster data of the patient with the simulated data, one can determine whether the simulation corresponds to the pathology of the patient. The 3D representation of the patient offers an additional support regarding the evaluation of a simulation.

3. Comparison of Simulation Results with Patient Data

The comparison is related to the Hess-Lancaster test mentioned before, whereby the process of comparing can also serve as a verification of the diagnosis posed before. Thus, in this step it is to determine whether the simulation result agrees sufficiently with the measured patient data. This, at the same time, offers a basis for a later simulated treatment by interactive virtual surgery of the modeled pathology.

4. Simulation of a Surgery

In this step, the actual surgery is simulated by interactively modifying different model parameters using the mouse within the 3D representation. Points of reference support orientation and the dosage of the surgery performed. Furthermore, different surgery techniques like anterior/posterior transposition and tangential transposition of muscle insertions are supported. Muscle force or innervation related parameters are modified manually in the program so that they correspond to a comparable surgical procedure. For example, a muscle resection can be accomplished by changing the parameters of a muscle representing the tendon and muscle length. The 3D-model visualizes these modifications immediately after confirming the entered values.

5. Evaluation of Results

As in step 3, a comparison of the simulation results is carried out again. On the basis of the binocular Hess-Lancaster test, the outcome of a surgery can be evaluated regarding to the correction of a pathological situation and whether it is still necessary to apply additional changes (simulation trials).

6. Simulation Result

The simulation result represents the last state of all model parameters in the task flow of the simulation of a pathology and surgery with SEE++. The system offers the possibility to assign and archive these results to a patient in the form of so-called scenarios. That way the results of different simulations can be compared with each other and e.g. simulation strategies can be developed. Each scenario stores an arbitrary step of a patient treatment and can later be accessed again in textual or graphical form.

Part II

2 Mathematical Models

2.1 Overview

A first "attempt" for the development of a mathematical model of the human eye was formulated by Krewson in 1950. This model defined exclusively geometrical relations and was improved by Robinson in 1975. A few years later in 1984 a first complete biomechanical model was introduced by Miller and Robinson, which additionally supported muscle forces and kinematics as well. This model was called SQUINT and later it was refined in a second, very similar version. Based on the models described so far, Günther implemented a new biomechanical model in 1986 using geometrical formulations from Kusel and Haase (1977). This model was also implemented as a computer system, but the model predictions could not be correlated with clinical experience.

In 1995, Miller and Demer introduced a new biomechanical model and computer system called Orbit™ (further information can be found at www.eidactics.com). This system was the first computer simulation, which also considered anatomic elements like pulleys and so provided significantly better model predictions that were even comparable to clinical data. At the same time Orbit™ was the first computer system with a graphical user interface in this field.

In the year 2000, the biomechanical model "Eyelab" was introduced by Porrill, Warren and Dean. This implementation could only be used for research purposes and was implemented with Matlab. This model does not provide a clinical test and therefore cannot be used for the modeling of pathological situations.

The SEE-KID model, which is the model primarily used in SEE++, is partially based on the formulation of "Eyelab" and "Orbit". The Orbit model was additionally implemented in the SEE++ system in an unmodified form in order to enable comparisons between different simulations. The SEE-KID model was developed using modern methods of software engineering as well as object and component-oriented technologies. Compared to others, this model is characterized by the fact that it realizes an abstract definition of a biomechanical eye model. Thus, several instances of different models (SEE-KID model, SEE-KID active pulley model, Orbit model, string model and tape model) can be realized and subsequently compared. The biomechanical eye model formulated in the context of the SEE-KID research project nevertheless is a full, mathematical solution for the proposed problem and it uses non-linear optimization strategies for solving a kinematic system. Furthermore, it defines an independent geometrical model.

The SEE-KID active pulley model is also an independent model within the SEE++ system, which is based on the SEE-KID model. Additionally, this model implements the "Active-Pulley-Hypothesis" formulated by Demer et. al., which describes the active movement of the pulleys of the straight eye muscles in secondary and tertiary gaze positions.

In contrast to other simulation systems, SEE++ offers an intuitive graphical user interface, which allows the usage of nearly all functions of the system (parameterization, simulation, surgery) interactively with a 3D-model.

As mentioned before, the SEE++ system includes different mathematical models of research history and provides interactive comparability of simulation results among different model-based calculations. SEE++ implements five different models from which two models simulate purely geometrical characteristics of the oculomotor system.

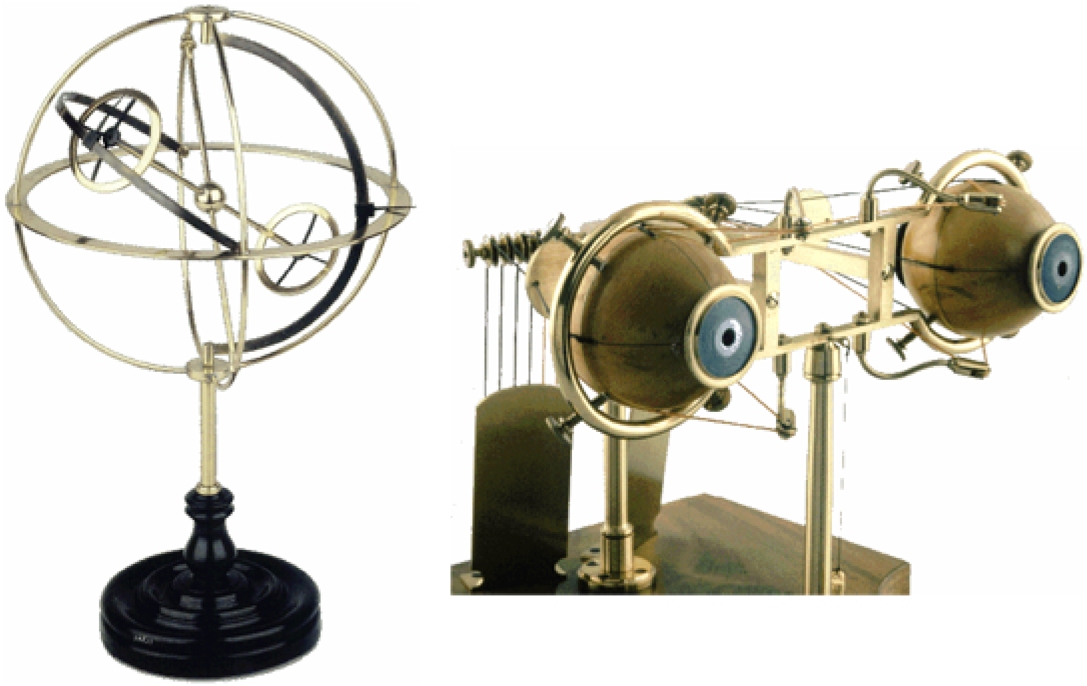
Type of Model	Geometry	Muscle Forces	Kinematics
String Model	✓	✗	✗
Tape Model	✓	✗	✗
Orbit Model	✓	✓	✓
SEE-KID Model	✓	✓	✓
SEE-KID Active Pulley Model	✓	✓	✓

Different Model Types Included in SEE++

The fact that the purely geometrical models do not contain force simulations and kinematics leads to the restriction that a binocular test of eye motility, like the Hess-Lancaster test, cannot be simulated with these models. Nevertheless, string and tape model offer an ideal introduction to a better understanding of the oculomotor system and its underlying geometrical characteristics.

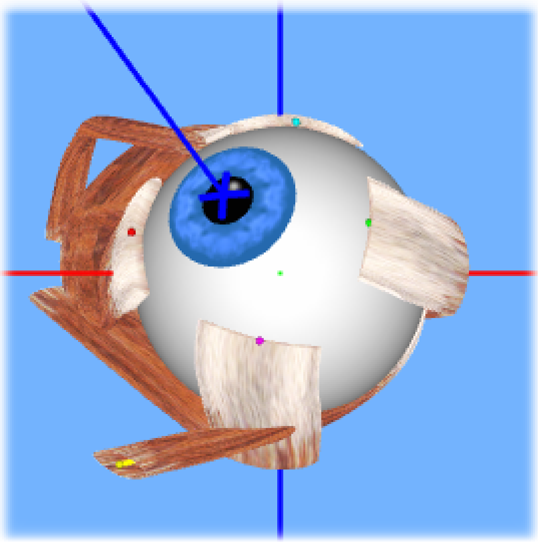
2.2 Geometrical Models

SEE++ implements purely geometrical models (string model and tape model) as well as kinematic models with geometrical components (SEE-KID model, SEE-KID active pulley model and Orbit model). For the coordinate systems and the descriptions of eye positions and rotations, common guidelines known from eye research history are used.
One of the first attempts to get a better understanding of eye motility were the so-called ophthalmotropes. In 1845, Ruete designed a mechanical model of the human eye usually built out of wood and strings, in order to make it easier to study the basic principles of eye movements. In 1848, F. C. Donders introduced Donders' law: If the eye fixates an object somewhere in space, the position of this object also determines the gaze position of the eye. But the position of the object in space does not specify the amount of torsional rotation, nor is this amount of torsion arbitrary. In fact, the amount of torsion is clearly specified through the gaze position of the eye itself.



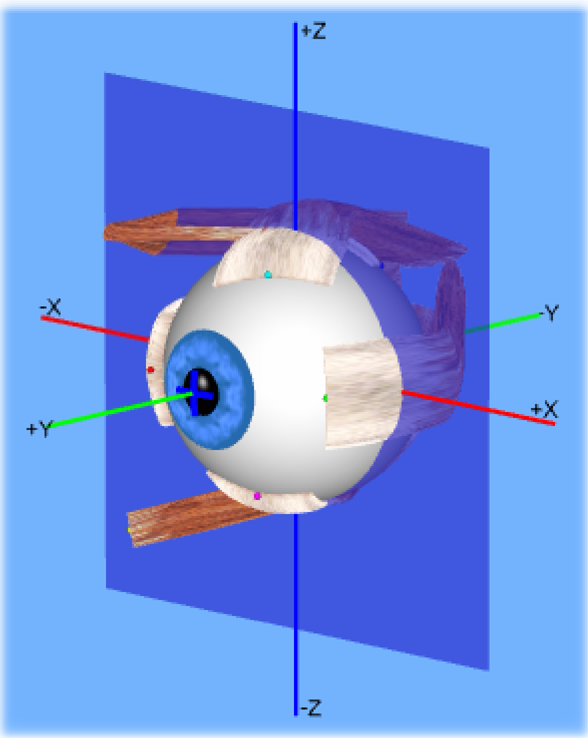
Halle's and Ruete's Ophthalmotrope [Simonsz and Tonkelaar, 1990]

When the German edition of Donders' work was published, it attracted the attention of H. Helmholtz, who found an explanation for the discovery of Donders. He termed the torsional rotation of the globe found by Donders as "Pseudotorsion", which results from a measurement error but actually does not really exist. Pseudotorsion is caused by the fact that, in tertiary gaze positions, the vertical meridian through the eye does not coincide with a vertical line in space, nor does the horizontal meridian coincide with a horizontal line in space. The reason for this discrepancy is that the meridians (cross on the cornea in SEE++) are defined in a globe-fixed coordinate system.



Pseudotorsion in Tertiary Gaze Position

Since pseudotorsion is caused by an unsuitably defined coordinate system, in 1853 J. B. Listing had the idea to use a polar coordinate system to overcome this problem. Thereby, he also discovered that all tertiary positions of gaze can be reached by a single rotation around one particular axis out of the primary position and moreover that all these rotation axes are part of the same plane (Listing's plane) with a constant torsional angle. This discovery was termed as Listing's law. Listing's law always describes the same torsional angle in a certain eye position, regardless of how this gaze position has been reached.

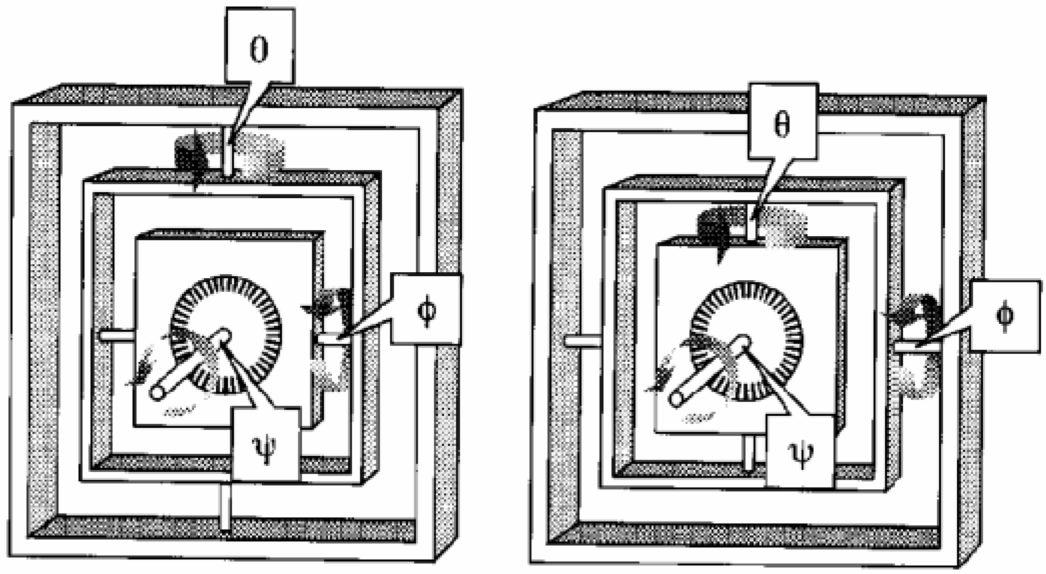


Listing's Plane of a Healthy Left Eye

As mentioned before, Listing's plane can be characterized by a visualization of the end points of the rotation axes which describe a 3D eye position starting from the primary position going into any other eye position. For a healthy eye, this plane lies parallel to the X-Z plane of the coordinate system (see figure). For a pathological eye, the plane is tilted according to the torsional effects of the particular pathology. Listing's plane can be visualized 126 in the 3D-view of SEE++ according to the currently simulated pathology.
When Donders' law and Listing's law were published, there was a great demand for a standard definition for describing eye positions regarding the sequence of rotations around the different coordinate axes.

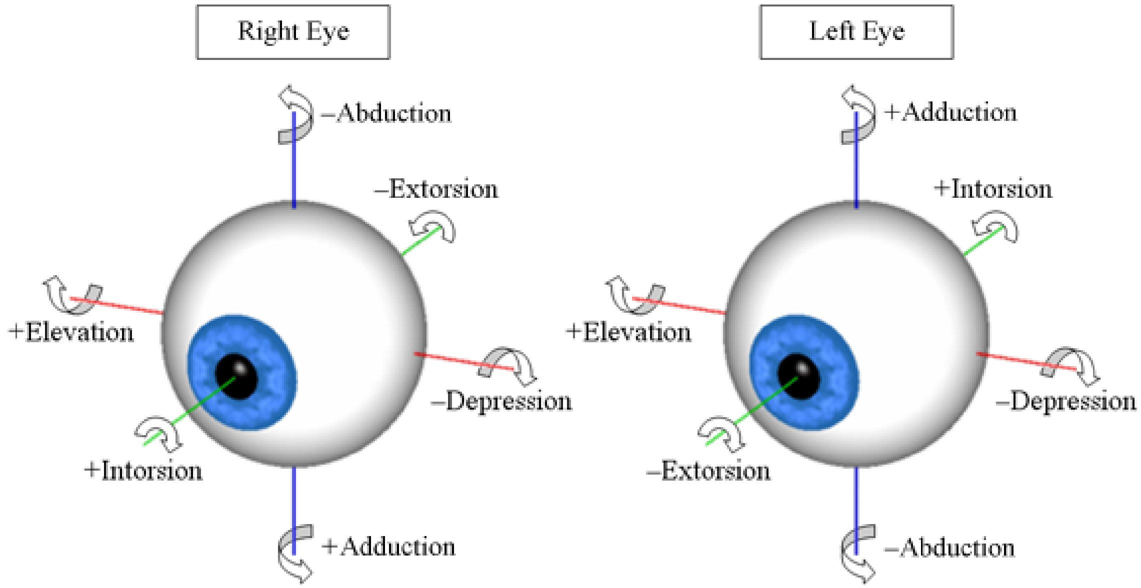
Geometrical Description of Eye Positions

Due to the non-commutativity of rotations in 3D space, it is necessary to use a standardized sequence of rotations in order to describe eye positions. For any eye position described by three component angles, also the applied sequence of rotations has to be specified. In 1854, A. Fick defined the so-called Fick sequence of rotations, where the first rotation has to be carried out around the vertical axis, then around the horizontal and finally around the torsional axis. In contrast, Helmholtz defined the sequence of rotations first around the horizontal, then around the vertical and finally around the torsional axis. Both rotation sequences describe a gimbal-mounted globe considering the particular sequence of rotations. From the illustration of the two systems (see following figure) it is easy to see that some specified angles of an eye position lead to different positions of the globe and thus to different eye positions when comparing both systems.



Gimbal Mounting According to Fick (Left) and Helmholtz (Right)

The SEE++ system generally uses the rotation sequence of Fick, which divides an eye position into three rotation angles, first around the vertical axis, then around the horizontal axis and finally around the torsional axis.
For a complete definition of eye positions, the used coordinate system is also of importance. The following figure visualizes the coordinate axes together with their algebraic signs and directions for both eyes.



The Six Possible Rotation Directions of the Eyes

The coordinate system used for the extorsion is different for both eyes in terms of the ab-/adduction axis and the in-/extorsion axis. Directions of rotation around the respective axes can be described as follows (in the figure above the nose is assumed between the two eyes):

1. **Rotation around z-axis (duction, blue)**
   positive angle = adduction (towards the nose)
   negative angle = abduction (away from the nose)

2. **Rotation around x-axis (elevation, red)**
   positive angle = elevation (upward)
   negative angle = depression (downward)

3. **Rotation around y-axis (torsion, green)**
   positive angle = intorsion (inward rolling)
   negative angle = extorsion (outward rolling)

As shown in the figure above, the coordinate axes for ab-/adduction and in-/extorsion point in different directions for both eyes. This allows a standardized definition of the angle direction with consistent descriptions (e.g.: abduction = away from the nose). In both eyes, positive torsion is defined to rotate the eye inward around the line of sight. If the two axes did not have different signs, an intorsion of both eyes would mean that one eye rolls outward and the other one rolls inward. The axes for elevation and depression remain the same in both eyes, since up and down rotations specify the same directions for both eyes.

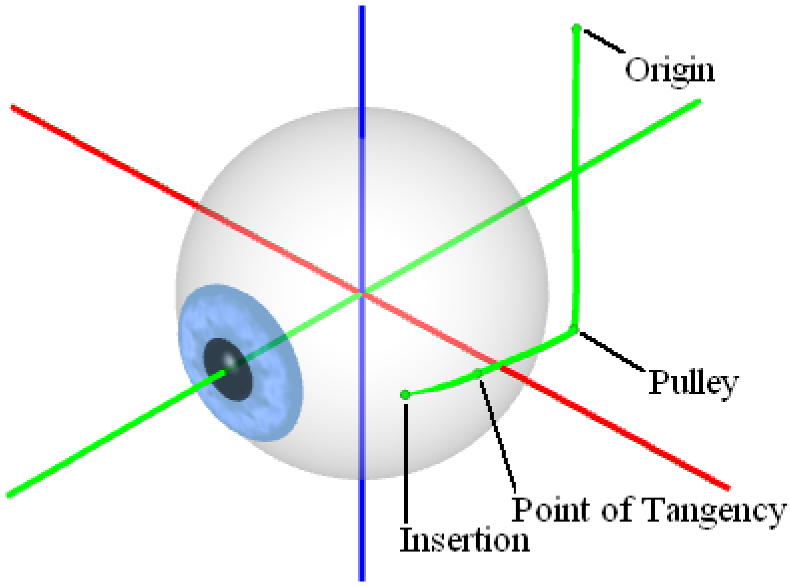
Additionally, in case of binocular eye movement, abduction of one eye results in adduction of the other eye, thus eye positions have to be mirrored for ab-/adduction and in-/extorsion movements.

Globe Translation

Within the orbita, the eye is surrounded by flexible fat pads, which, besides rotation, permit globe translation up to a certain degree. Usually, this translation is negligibly small, however in some pathological situations involving co-contraction of muscles (e.g. Duane syndrome), additional information about globe translation becomes an important indication for the estimation and correction of a motility disorder. The SEE++ system calculates globe translation on demand and visualizes it in the 3D-view, whereby a forward movement of the globe along the y-axis is denoted as protrusion (globe translation with positive sign) and a backward movement is defined as retraction (globe translation with negative sign). The respective values for protrusion and retraction are shown in a textual form in the system for each eye position. In the 3D-view the user can choose whether to include globe translation in the visualization 111.

Geometrical Description of Muscle Action

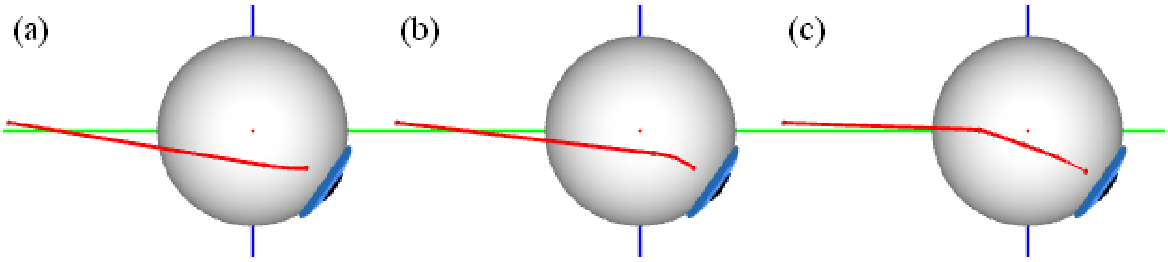
In order to complete the definition of extraocular geometry, one also needs to consider the geometrical properties of muscles and their directions of pull. The geometrical description of a muscle is based on the definition of important designated points, whereas a muscle's force direction is specified by the definition of a rotation axis, around which a single muscle would rotate the globe. The geometrical description of a muscle is defined by a muscle path from the origin to the insertion. Attention should be paid to how this muscle path changes with different gaze positions and how it adapts to the position of the globe respectively.



Definition of Muscle Path

The figure shows the path of the outer straight muscle (lateral rectus muscle), defined by origin, pulley, point of tangency and insertion. The muscle origin lies in the area of the posterior end of the orbita in the annulus of Zinn (Zinn's ring). The pulley stabilizes the muscle path in the rear area of the orbita. This point is not used in the string or tape model, since these two models assume a definition of the muscle path without pulleys. The point of tangency marks the area, where the muscle path first touches the globe. The distance between insertion and point of tangency is called arc of contact.

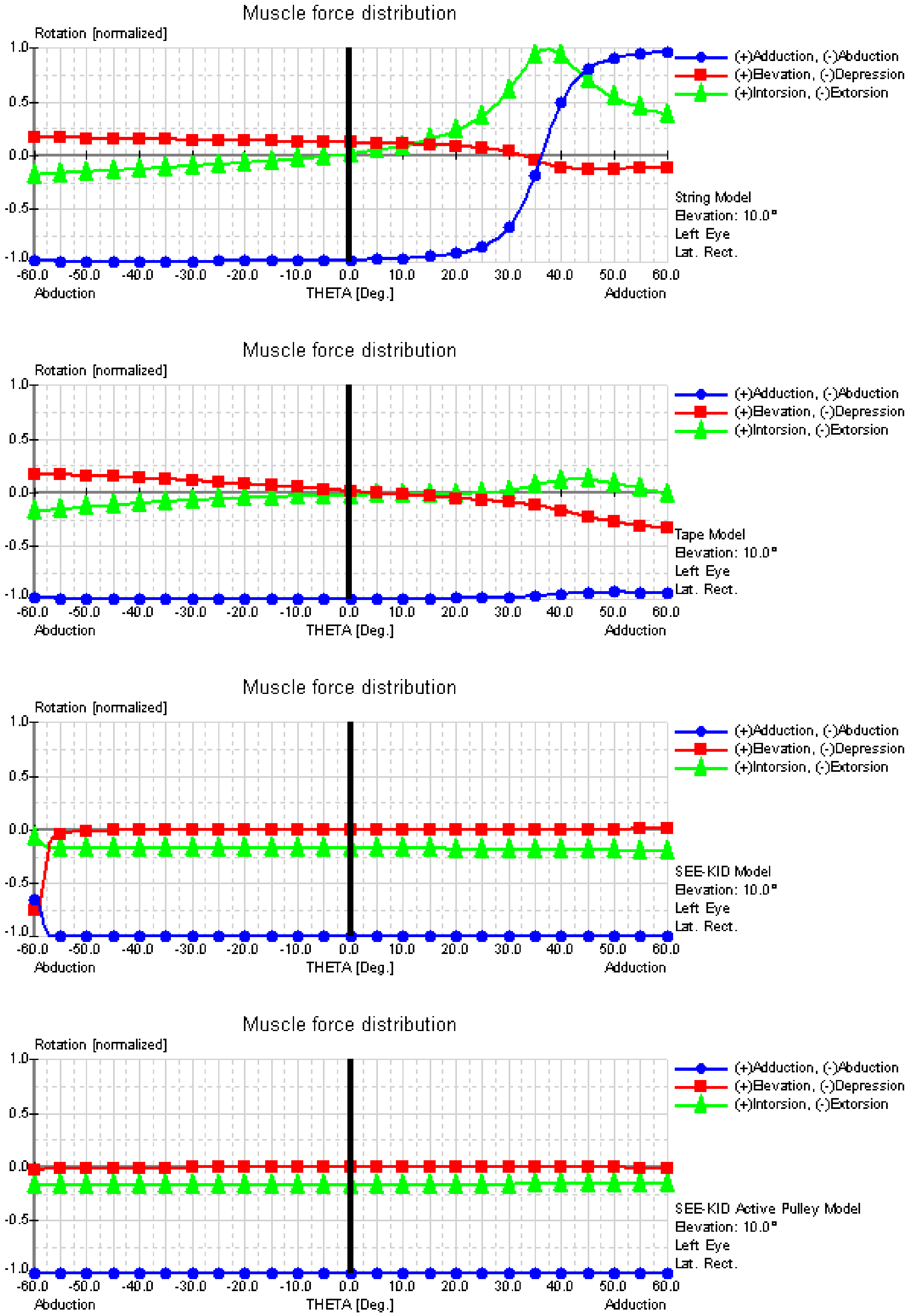
Reactions of the muscle path to changes in gaze position are differently represented by different models. Thus substantial differences exist in the definition of the muscle path between string model, tape model, Orbit model and SEE-KID model. String model and tape model exclusively use the anatomical origin of the muscle, the point of tangency and the insertion for the definition of the muscle path. However, SEE-KID model and Orbit model additionally consider pulleys. In the SEE-KID active pulley model, the pulley is finally even moved together with the globe.



Comparison of (a) String Model, (b) Tape Model and (c) SEE-KID Model

In comparing the muscle path representation of these models (see figure), noticeable differences in representing the movement of the point of tangency occur. In the string model (a) as well as in the tape model (b), the point of tangency and hence the whole posterior muscle path moves downwards together with the globe. This also affects the direction of pull significantly in other gaze positions. Here the SEE-KID model (c) provides a much better prognosis. The introduction of pulleys results in a stabilization of a muscle's direction of pull and therefore a substantially more realistic prognosis can be made.

The description of the rotation axis of a muscle and therefore also the rotational effect of a muscle onto the globe are derived from the muscle path. The rotation axis of the string model and the tape model is perpendicular to the plane defined by insertion, point of tangency and origin. In the Orbit, SEE-KID and SEE-KID active pulley model the pulley point is additionally considered. The direction of pull of a muscle (rotation axis) can be represented in all three components (x, y, z) in a diagram, in order to get a better estimation of the rotational effect. The x-component of the rotation axis represents the portion of the elevation/depression that a muscle exerts on the globe, the y-component gives information on intorsion/extorsion and the z-component describes abduction/adduction.



Muscle Force Distribution of the Lateral Rectus Muscle in the String, Tape, SEE-KID and SEE-KID Active Pulley Model

The muscle force distribution shows the relative rotational components for selected eye muscles along a horizontal view range (see figure) in a certain level of elevation or depression. The rotational components are indicated in standardized values between -1 and +1 for ab-/adduction, elevation/depression and in-/extorsion. The figure shows the force distributions of the lateral rectus muscle in the string, tape, SEE-KID and SEE-KID active pulley model with an elevation of 10 degrees along the horizontal view range (0.00-line in the figure) with up to 60 degrees abduction and adduction of a left eye.

Here, the physiologically incorrect prediction of the string model becomes clearly evident at approximately 36 degrees of adduction, where the lateral rectus muscle drastically changes its abducting effect into an adducting effect. In comparison with the tape model, a significantly better physiological muscle force distribution for the exact same scenario is shown by keeping up the main direction of pull of the lateral rectus muscle. These differences result from the differentiated mathematical modeling of the anatomical structures. In the string model, the muscle path in the contact area of the globe is defined by the shortest path between insertion and origin. In contrast, the tape model contains an angle-reducing component, which describes the muscle path by the relative movement of the point of tangency as a function of gaze position. This allows the simulation of stabilizing connective tissues and supporting ligaments in order to limit the movement of muscles in extreme gaze positions. Graphically, this simulation results in a bent muscle path between insertion and point of tangency, which substantially better, but not optimally, corresponds to anatomical conditions.

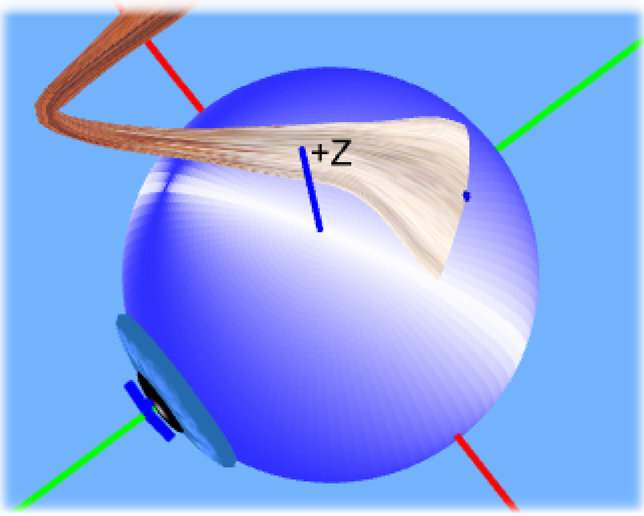
Only by the introduction of a model that considers pulleys, more detailed simulations and pathological case studies can be accomplished. The mathematical basis for such a model is the introduction of an additional functional origin (pulley) directly behind the anatomical equator of the globe. This results in a stabilization of the muscle path in the rear area of the orbita and the functional origin is now used for the definition of the muscle force distribution. The anatomical origin is mathematically not so important for defining the direction of pull depending on the gaze position. The simulation of pulleys in the SEE-KID model (as well as in the Orbit model) shows a significantly better stabilization of a muscle's main direction of pull in the muscle force distribution. However, at about 55 degrees there is still a slight change of the muscle's main direction of pull. With the introduction of "active pulleys", which are pulleys that change their position according to the current gaze position (SEE-KID active pulley model), the muscle force distribution shows a complete stabilization of a muscle's main direction of pull over the entire physiological range of vision from -60 to +60 degrees. Therefore, the SEE-KID active pulley model is the currently most suitable (geometrical) model.

Functional Topography

The functional topography makes it possible to project the muscle force distribution onto the surface of the globe as a color-coded 3D visualization for all possible insertions of a muscle. Therefore, the insertion of a selected muscle is "virtually" moved to different locations on the globe and at each possible insertion the different rotational components (ab-/adduction, elevation/depression, in-/extorsion) are drawn onto the globe as color-coded brightness values (darker brightness values correspond to a high rotational component if the insertion of the selected muscle is moved to the respective location). The mapping of the different brightness value colors to the corresponding rotational components is the same as in the muscle force distribution diagram, which means that blue represents duction, red represents elevation/depression and green represents torsion. If more than one rotational component is shown at the same time, the colors of the selected rotational components are combined resulting in mixed colors.

By using this color-coding, it is now possible to find an "ideal" muscle insertion line for a certain muscle, where a certain rotational component should either be minimal (white or bright area on the globe) or maximal (dark area in the appropriate color on the globe). If the visualization of several rotational components is combined, intersection points can be found, where several components are minimal or maximal at the same time. These "ideal" insertion lines and intersection points in combination with the poles of the globe and the coordinate axes offer a useful support for planning surgeries.

The following figure shows the distribution of the horizontal rotational components (blue) of the left superior oblique muscle in primary position. Dark blue areas represent possible insertion positions, where the muscle would strongly rotate the eye into ab-/adduction, light blue or white regions represent areas, where the muscle would only little or not at all rotate the eye into ab-/adduction. Compared to the muscle force distribution diagram (MFDD - see definition of muscle force distribution 33) the direction a muscle would rotate the eye cannot be seen when using the functional topography (thus if a muscle with its insertion moved into an e.g. blue area would rotate the eye into adduction or abduction). The functional topography can be enabled in SEE++ by using the 3D-view options toolbar 126.



Functional Topography of Superior Oblique Muscle (Ab-/Adduction Component, Horizontal)

Geometrical Measurement of the Eye

Around 1989 a statistical analysis of several patients was carried out by A.W. Volkmann. The results of this study were published as data for a so-called "standard eye", which represents an average human eye. Based on Volkmann's data, the string model and the tape model were formulated. Later these basic geometrical data were extended, modified and the geometrical data of pulleys were added by Robinson and Miller.

These geometrical data have to be used according to the already defined coordinate system (see geometrical description of eye positions 28). SEE++ also offers a standard scenario containing the geometrical data by Volkmann.

	Origin (x / y / z) in mm	Insertion (x / y / z) in mm
Globe Radius:	12.43 mm	
Cornea Radius:	5.50 mm	
medial rectus m.	-17.00 / -30.00 / 0.60	-9.15 / 8.42 / 0.00
lateral rectus m.	-13.00 / -34.00 / 0.60	10.44 / 6.75 / 0.00
superior rectus m.	-16.00 / -31.78 / 3.80	0.00 / 7.33 / 10.05
inferior rectus m.	-16.00 / -31.70 / -2.40	0.00 / 7.65 / -9.80
superior oblique m.	-15.27 / 8.24 / 12.25	-0.07 / -8.05 / 9.48
inferior oblique m.	-11.10 / 11.34 / -15.46	6.73 / -10.46 / 0.00

Geometrical Data According to Volkmann

The discovery of pulleys as functional elements in 1989 (Miller and Demer) revised these data:

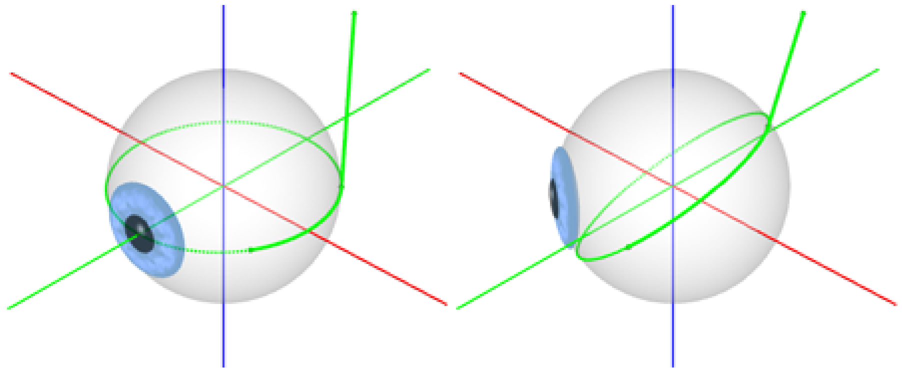
	Origin (x/y/z) mm	Insertion (x/y/z) mm	Pulley (x/y/z) mm
Globe Radius:	11.99 mm		
Cornea Radius:	5.50 mm		
medial rectus m.	-17.00/-30.00/1.00	-9.65/8.84/0.00	-14.00/-5.00/0.14
lateral rectus m.	-13.00/-34.00/-1.00	10.08/6.50/0.00	12.00/-8.00/0.33
superior rectus m.	-15.00/-31.76/3.60	2.76/6.46/10.25	-5.16/-10.78/10.00
inferior rectus m.	-17.00/-31.76/-2.40	1.76/6.85/-10.22	-5.16/-8.78/-12.00
superior oblique m.	-18.00/-31.50/5.00	2.90/-8.00/8.82	-15.27/11.00/11.75
inferior oblique m.	-13.00/10.00/-15.46	8.00/-9.18/0.00	-13.00/10.00/-15.46

Geometrical Data According to Miller and Demer

Here the muscle insertions as well as the pulley positions were measured in three dimensions. This means that, with the geometrical abstraction to assume the globe as a spherical object, each muscle's insertion does not lie exactly on the globe, due to the fact that in reality the globe is shaped like an ellipsoid. This leads to a compromise in choosing the globe radius as the smallest distance between coordinate system origin and muscle insertion of all six muscles. The so-called "muscle-based globe radius", as well as the "actual" globe radius, can be easily changed by modifying the corresponding parameters in SEE++. The significant mathematical difference of these data is caused by the fact that now each muscle rotates its own "virtual globe", in turn affecting lever arm and force behavior.

2.2.1 String Model

The string model is the simplest representation in order to describe the geometrical effect of eye rotations. It was formulated by Krewson in 1950. According to the string model, a muscle is assumed as a thin string with an insertion on the globe and an origin located in the posterior end of the orbita. Krewson assumed that the strings are always pulled tight and therefore the muscle path is the shortest path between origin and insertion.

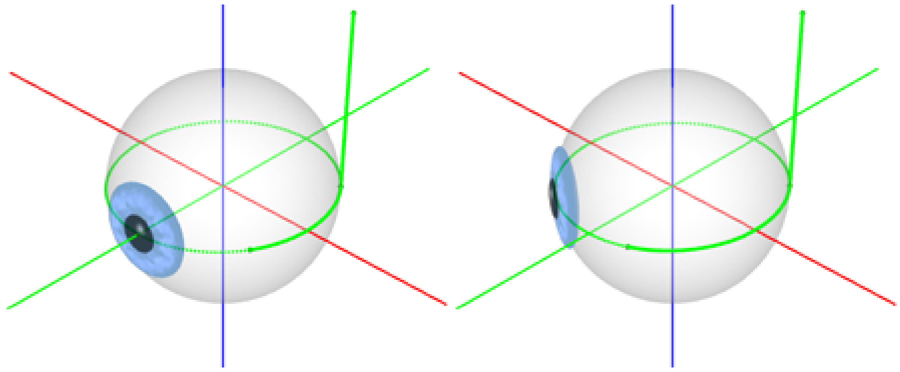


Muscle Path of the String Model in Primary (Left) and Secondary Gaze Position (Right)

Since the muscle path in this model describes the shortest path from origin to insertion, the circle that describes the muscle action on the globe always forms a great circle (muscle action circle, see figure). This makes the calculation of the point of tangency much easier.
Using the string model, model predictions hardly correspond to clinical expectations, especially in secondary and tertiary gaze positions. Only in primary position the string model provides acceptable predictions for muscle path and muscle action. The left part of the above figure shows a left eye with the lateral rectus muscle in primary position, whereas the right part shows an adduction of 35° (secondary gaze position). It is easy to see that the path of the lateral rectus muscle "shifts" upwards as the eye looks into adduction, which does not correspond to clinical observations. This shift results in a drastic change of the muscle path and thus in an abnormal rotation of the eye (the lateral rectus muscle suddenly becomes an elevator!). The lateral rectus muscle cannot keep its mainly abducting effect on the globe, it "slips" away as the eye turns towards the nose.

2.2.2 Tape Model

Based on the string model, Robinson formulated the so-called tape model in 1975. This model reduces the shift of a muscle's path on the globe by the introduction of an angle reduction in secondary and tertiary gaze positions. Thus, the movement of the point of tangency on the globe is described by a linear, eye position-dependent value. Due to this modification, the muscle action circles of the string and the tape model do not coincide anymore. Only in primary position the muscle action circle forms a great circle on the globe in both models, since the angle reduction only has an effect in gaze positions different from the primary position. In all other gaze positions, the muscle action circle is a small circle on the globe, whose center does no longer coincide with the rotation center of the globe. The definition of the muscle action now also includes the point of tangency, leading to a clear change in model prediction.

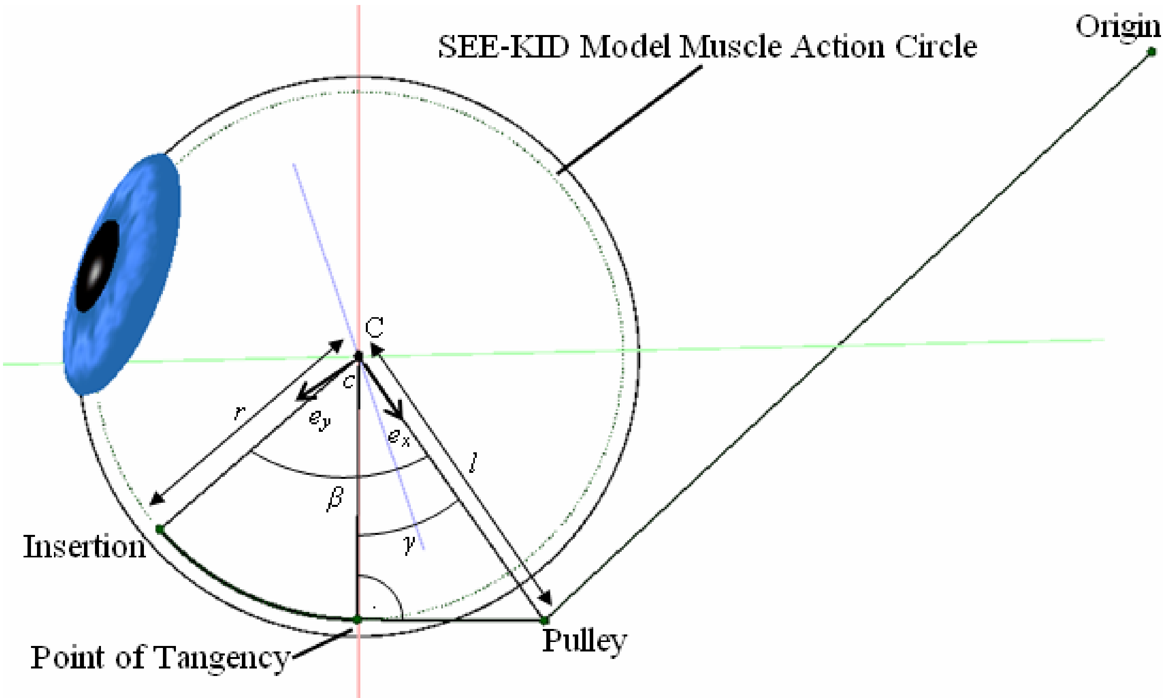


Muscle Path of the Tape Model in Primary (Left) and Secondary Gaze Position (Right)

Limiting the movement of the point of tangency reduces the muscle shift in secondary and tertiary positions. The figure shows this effect for the lateral rectus muscle of a left eye in primary position and after an adduction of 35°. Nevertheless, the model predictions are not satisfying compared to clinical measurements.

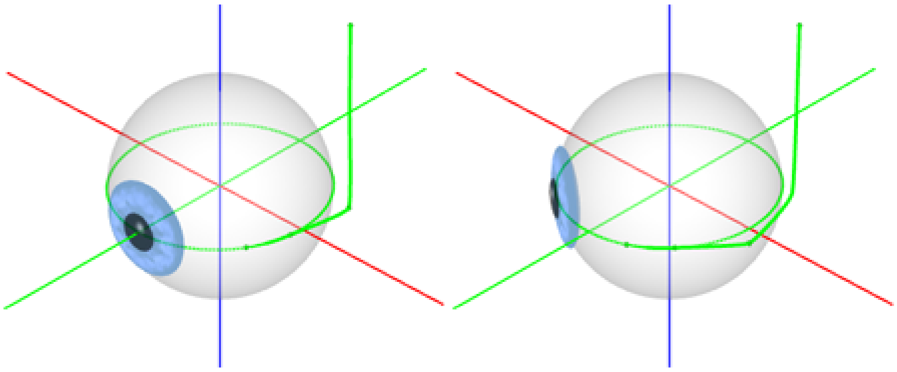
2.2.3 Pulley Models

The SEE++ system implements 3 models that consider pulleys, namely the SEE-KID model, the SEE-KID active pulley model and the Orbit model. These models define a pulley as an additional point for the geometrical definition of the muscle path. The pulleys as functional elements were discovered by Miller and Demer in 1989 and were measured three-dimensional with the help of MRI (magnetic resonance imaging) and histological research. By the additional introduction of a pulley, a muscle hardly moves in the rear area of the orbita when the eye changes its position. The functional origin, i.e. the point of interest for the calculation of the main muscle action, is now not the anatomical origin, but the pulley. This causes a strong stabilization of the muscle in its path from the pulley to the insertion with the effect that the muscle in extreme gaze position maintains its main direction of pull.



Muscle Path of the SEE-KID Model

The models that consider pulleys provide the best predictions in regard to their geometrical behaviour in comparison with clinical data so far. The finding that a pulley as supporting ligament can be seen as an additional anatomical structure of the eye also solved many open questions regarding clinical, surgical aspects. Furthermore, pulleys are elastically coupled to the orbital wall and, in far tertiary gaze positions, they can slightly shift in order to affect and correct the muscle path (basis of the "Functional Topography" 33). This characteristic contributes substantially to the mechanical stabilization of muscle action and, as a consequence, the entire oculomotor apparatus.

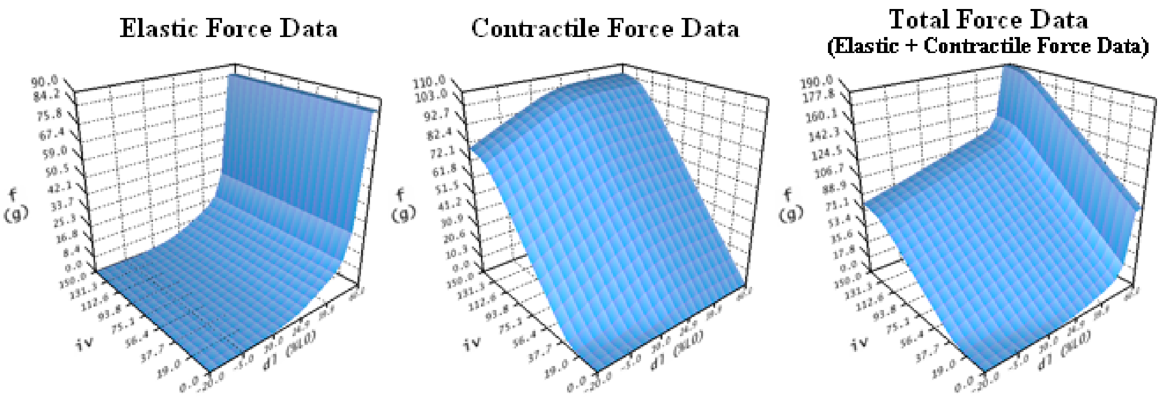


Muscle Path of the SEE-KID Active Pulley Model in Primary (Left) and Secondary Gaze Position (Right)

The SEE-KID active pulley model, in contrast to the SEE-KID model and the Orbit model, does not simulate the pulleys as fixed static elements, but as elements which actively move with the eye. So for example the pulley of the lateral rectus muscle moves forward, if the eye looks in adduction (see figure) and backwards, if the eye moves in abduction. By this movement, the main muscle action is optimally maintained even in extreme gaze positions.

2.3 Kinematic Model

In order to be able to completely simulate a mechanical system, apart from geometrical structures, the simulation of forces is also needed. The force development of extraocular muscles is described by an isolated force model, providing specific behavior patterns for each muscle. The structure of the model orients itself on already existing model types for the skeletal musculature. Here the muscle function is divided into elastic (passive) and contractile (active) force development. Elastic forces are developed due to stretch and compression of the muscle, while contractile forces always presuppose a neurophysiological activation potential. The resulting total force function adds up contractile and elastic force functions and simulates the actual impact of a muscle.

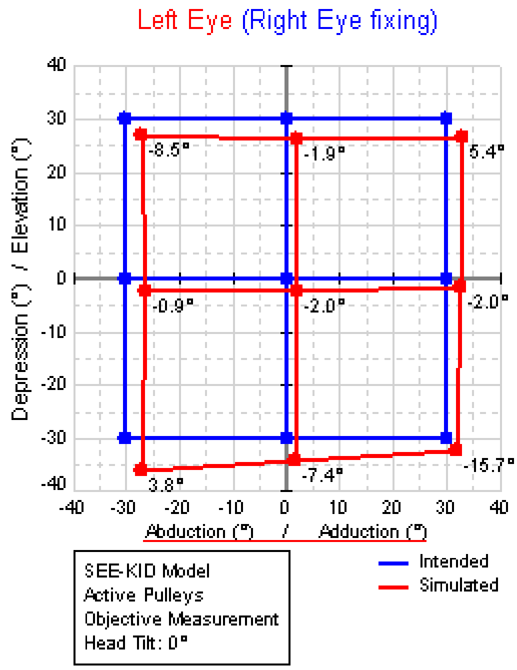


Muscle Force Simulation of Lateral Rectus Muscle (Based on Orbit™, See [Miller, 1999])

The functions shown in this figure describe the static force development of a muscle concerning a well-defined force-length-innervation relationship. While the elastic force development (f in grams) is defined exclusively in dependence of the length variation of a muscle (dl in percent of L0), the contractile force function (f in grams) is additionally dependent on the innervation (iv). The muscle force simulation of all other extraocular muscles is implemented as relative scaling of the data displayed in this figure. The underlying data were defined according to research of Miller and Robinson.

The geometrical model and the model for the muscle force simulation described so far are now connected by the introduction of a kinematic model. This kinematic model is responsible for the transmission of forces in the geometrical model. To achieve this, each muscle's rotation angle around its geometrical axis is put in relation to the predicted force development. The result is a rotation axis with an associated rotation angle, which describes the current mechanical impact of all six eye muscles in a certain gaze position. If a rotation of the globe into the predicted direction is carried out, again all components of the geometrical model and of the muscle force simulation change. As a result of the change in the geometrical model, the muscle force distribution also changes and due to the passive length change of the muscles the muscle force functions are modified and transitively result in a new force distribution. This process continues until a stable eye position can be achieved. Such a stable eye position is characterized by a force equilibrium of all six muscles.

With the help of this simulation technique, the problems of the forward and inverse kinematics can be solved. The forward kinematic finds the resulting gaze position with given innervations for all six eye muscles, whereby the inverse kinematic derives the innervations for all six eye muscles from a given gaze position. If these two methods are now combined, a test for the binocular examination of eye movement disorders can be simulated. The SEE++ system simulates the Hess-Lancaster test by displaying the standard gaze positions of one eye next to the pathological deviations of the other eye in different colors.



Hess Test with Standard Gaze Positions of a Non-Pathological (Right) Eye (Dark or Blue) and Gaze Positions of a Pathological Left Eye (Bright or Red).

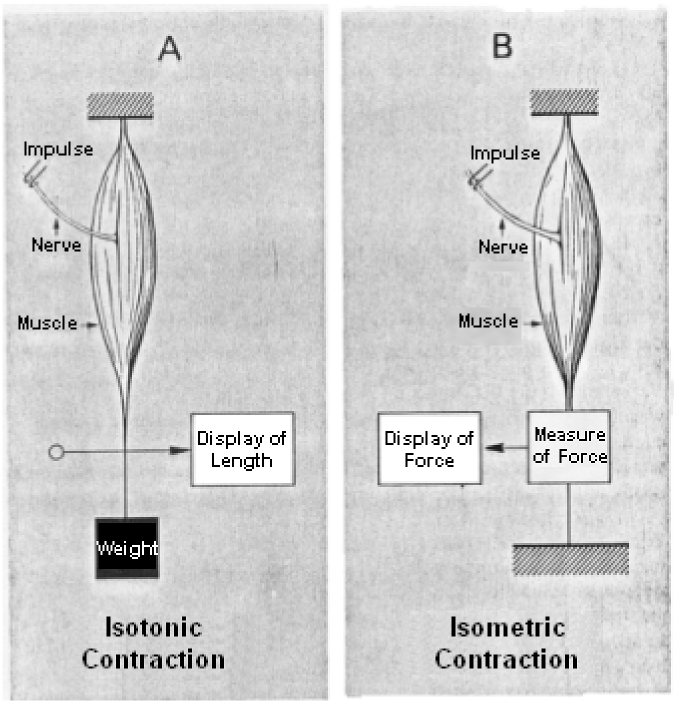
For each gaze position, the innervation pattern of all eye muscles of the fixing non-pathological eye is determined and subsequently passed to the pathological eye (Hering's law) in order to determine its resulting gaze position. The innervations are only defined for the agonistic muscles, the antagonistic innervations have to be calculated by application of a reciprocal innervation function (Sherrington's law). The result of the test can easily be seen by comparing the standard gaze positions with the pathological gaze positions of the examined eye: Slight diplopia in primary position, hyperfunction of the left eye in depression and abduction of the right eye, etc.

On basis of these models and their parameters, a pathological situation and/or a surgery is simulated. The changes in geometry directly affect the currently used geometrical model, as for example when transposing an insertion, the new insertion coordinates are directly applied and thus a new direction of pull of the muscle is defined. How the new muscle path will affect the mechanical behavior of the eye is highly dependent on the particular geometrical model that is used. For example, the string model provides a significantly "worse" anatomical representation than the tape model of Robinson.

2.3.1 Muscle Force Model

The goal of the muscle force model is to simulate the behavior of a muscle as a function of its length and innervation. This is achieved by the definition of three force functions (contractile, elastic and total force). In order to modify the behavior of a muscle for e.g. simulating muscle palsies (paresis) or hyperfunctions, the force model offers several different parameters, which change the shape of the simulation curves in certain ways in order to simulate the desired situation.

During the examination of muscle forces, one differentiates two types of muscle contraction: isotonic contraction and isometric contraction. An isotonic contraction is used for the measurement of the muscle length and length change due to an activation with constant load (see figure A). In case of the isometric contraction, the strength and the change of force of the muscle is measured with the length held constant (see figure B). The contraction mechanism takes place on molecular level and is described by the so-called filament sliding theory. Actin and myosin filaments are connected by so-called bridges and allow an activation-triggered shortening and thus the development of muscle strength.

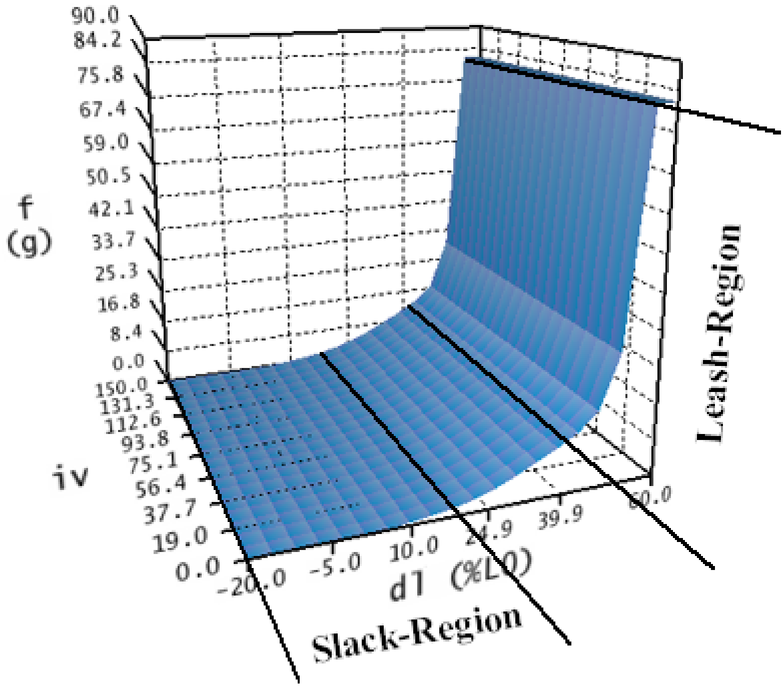


Different Types of Muscle Contraction Measurement

In general, static and dynamic characteristics of a muscle can be differentiated. Static force behavior is also called force-length relationship. As a starting point, an isometric force measurement is carried out and the measured force is recorded depending on the previously set (fixed) length. Dynamic characteristics of a muscle refer to contraction speeds and are analyzed by isotonic measurements. SEE++ currently represents only a static model of muscle force development and concentrates on the modeling of force-length-innervation relationships.

In the representation of static characteristics of a muscle, one differentiates again between contractile (active) and elastic (passive) muscle forces. Contractile muscle forces result from activation (innervation) of a muscle by the brain, while elastic forces represent the elastic stretch-characteristics of a muscle, which work opposite to the contractile forces. By applying repeated isometric force measurements with differently adjusted lengths, a force-length curve of the muscle behavior results. In relating these data to the activation potential of a muscle, a three-dimensional force-length-activation function is the result. This function again can be divided into its contractile and elastic forces receiving a contractile and elastic force curve, which together correspond to the total force curve of a muscle.

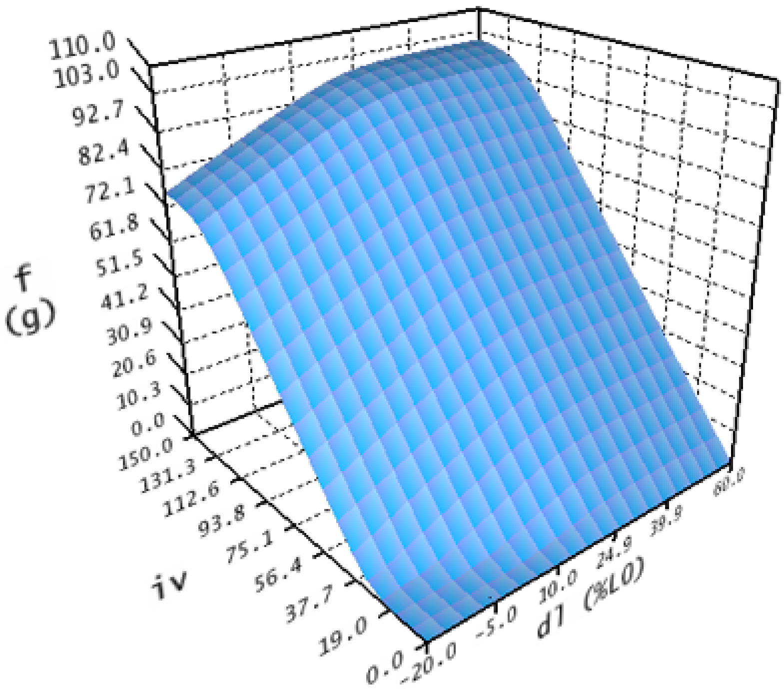
The elastic force curve describes the elastic forces, which the muscle exerts when it is stretched or compressed accordingly. If a detached muscle is sufficiently stretched, then, at a certain length, this muscle won't behave like a non-linear spring anymore, but will get stiff very fast, allowing no further stretching. This is called "leash-region" and becomes apparent in a drastic rise of the passive strength with increased stretch length. On the contrary, if a muscle is strongly pushed together in its length (shortened), then it will get slack and cannot exert force anymore. This is called the "slack-region" of the muscle force function.



Elastic Force-Length Curve

Like shown in the figure, the elastic force-length curve does not depend on the activation (iv) of a muscle, since only passive, elastic forces are modelled. This is also the reason why, for all innervations, the curve has the same shape in the length-innervation-plane. The elastic force curve is calculated in three intervals (dl < 17%; 17% <= dl <= 40%; dl > 40%) referring to the axis of the muscle's length. The unit used for this axis is the length change in percent referring to the relaxed, denervated length of the muscle (L0). In the first region (dl < 17%) the muscle force has been changed by hand to converge against zero, while in the third region (dl > 40%) the force was extrapolated up to a specific maximum in order to simulate the rapid increase of the stiffness of the muscle in the "leash-region". Between the first and the third region (17% <= dl <= 40%) the elasticity is calculated with a non-linear spring equation.

The contractile force curve now describes the resulting contractile force in dependence of innervation and length of a muscle.



Contractile Force Curve

This curve is also divided into three regions. The first region is calculated within the interval -20% <= dl <= 45% and 0 <= iv <= 100. The second region in the area of -20% <= dl <= 45% and iv > 100 is calculated by extrapolating the values from the first interval. The third region for dl > 45% is constantly calculated like dl = 45%.
The total force function is now calculated as the sum of the elastic and contractile force function.

In order to change the behavior of the extraocular muscles within the force model of SEE++, the system offers a number of parameters, which allow to manipulate the different curves. Three global parameters are available which influence all six muscles and specify the shape of the curves in the transition region between slack and leash region.

- Stiffness (g/% á L0) defines the rise of the curve towards the leash region, in order to approximate the overexpansion behaviour of the musculature. The unit therefore is gram per percent on the basis of the relaxed muscle length (L0). This value should only be changed in a very small range of 0 <= x <= 0.9.
- Force transition scaling (g) defines the shape of the curve at the transition to the slack region. The unit for this value is gram and it describes how much the curve is damped in the rising area of the calculated (second) interval. The smaller this value is, the longer the force is zero when the muscle is stretched. This also corresponds to a punctual expansion of the slack region.
- Force displacement ratio (% á L0) shifts the calculated (second) region of each curve on the axis of the muscle's length-change (dl). The displacement is specified in percent of the relaxed muscle length (L0).

Basically, the described parameters should only be used for experimenting with the force model of SEE++. These values should only be changed with the utmost care, because these changes strongly influence the simulation result.

Muscle-Specific Parameters

In the SEE++ system all six eye muscles are simulated with the described force model. The difference in the force development of each muscle is defined by two scaling factors (one for the elastic and one for the contractile force), which modify the force curves in relation to the lateral rectus muscle. The following parameters are available for each muscle:

- Elastic strength (%/100) scales the elastic force curve in order to influence the elastic properties of a muscle. A reduction of this value, for example, results in a muscle with a reduced elastic force when the muscle stretches.
- Contractile strength (%/100) scales the contractile force curve and simulates a hyperfunction or a muscle palsy in relation to the cerebral activation. A value of zero would correspond to a complete muscle paresis (complete loss of the contractile strength).
- Relative elastic strength (%/100 RL) scales the elastic force function with respect to the lateral rectus muscle. If this values is changed, a muscle is strengthened or weakened relative to the lateral rectus muscle; in order to modify the elastic strength relative to the current muscle, the parameter "elastic strength" should be directly used.
- Relative contractile strength (%/100 RL) scales the contractile force function with respect to the lateral rectus muscle. If this value is changed, a muscle is strengthened or weakened relative to the lateral rectus muscle; in order to modify the contractile strength relative to the current muscle, the parameter "contractile strength" should be directly used.

For the simulation of surgeries, the length of a muscle is also very important. The length of the muscle and the tendon also changes the way how the simulation system "interprets" the muscle force curves. The modification of muscle length (dl) is shown in percent in the muscle force curves. As an example, a rubber band with a length of 10 mm is used (relaxed length L0=10 mm). If this rubber band is stretched by 10 mm, one receives a path length of 20 mm and a relative stretch of 100%. If the band is now shortened to 5 mm relaxed length and once again the band is stretched by 10 mm, a relative stretch of 200% results. This would lead to a totally different resulting force in the force model and shows, how the modification of muscle length can influence the force behaviour of a muscle.

The muscle model of SEE++ offers the following parameters:

- Muscle length (L0) in mm specifies the length of a relaxed, denervated muscle without the tendon.
- Tendon length in mm specifies the additional length of the tendon.
- Tendon width in mm specifies the width of the tendon at the insertion and is used for the distribution of force over the muscle's width.

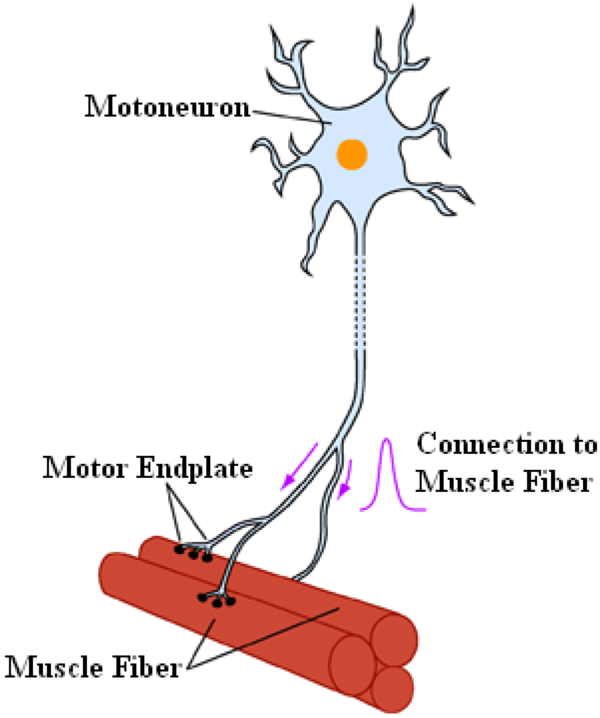
For example, to simulate a resection of the lateral rectus muscle by 5 mm, the length of the muscle and/or the tendon has to be changed accordingly. When the insertion of the lateral rectus muscle is separated from the globe, the muscle is shortened by 5 mm and afterwards the muscle is fixed again at the same position, one usually loses 1 mm of the length of the muscle and/or the tendon during the separation and 1 mm during the re-fixation (due to different surgery techniques, these values can vary and have to be corrected individually). Since SEE++ cannot consider these circumstances automatically, it is necessary to shorten the muscle by 7 mm in this situation.

Therefore, the tendon length of lateral rectus muscle would be changed from 7.71 mm to 0.71 mm. If a larger resection is carried out, it is possible that the muscle loses its tendon (tendon length = 0) and in such a case the remaining shortening has to be applied to the muscle length, consequently both parameters have to be changed. With the help of the surgery method "Resection", which can be carried out in the "Non-Graphical Surgery" 134 dialog, this reduction of the tendon length to 0 mm and the following reduction of the muscle length during a larger resection are made automatically.

Another parameter, which is only used in the Orbit force model, is the pulley stiffness. With this parameter, the passive movement of a pulley is limited in g/mm. Changes to this parameter and, as a consequence, the movement of the pulley in different gaze positions, affect the direction of pull of a muscle and transitively affect the muscle's force behaviour.

Innervation of Eye Muscles

The eye muscles are innervated by three cranial nerves. The nervus oculomotorius (III. cranial nerve) innervates the medial rectus muscle, the superior rectus muscle, the inferior rectus muscle and the inferior oblique muscle (moreover the levator palpebrae as well as - with its parasympathetic part - the ciliaris muscle and the sphincter pupillae muscle). The nervus trochlearis (IV. cranial nerve) innervates the superior oblique muscle and the nervus abducens (VI. cranial nerve) innervates the lateral rectus muscle. Each eye muscle is innervated by approximately 1000 motoneurons. The single motoneurons branch out into the eye muscle and innervate approximately 4 to 40 muscle fibers at a time. A motor unit is the aggregation of those muscle fibers, which are connected to one and the same motoneuron.



A Motor Unit of a Muscle Consists of a Motoneuron with All Muscle Fibers Innervated by This Neuron

The brain uses two different possibilities to increase the traction force of a muscle:

1. it recruits motor units, which were inactive before and

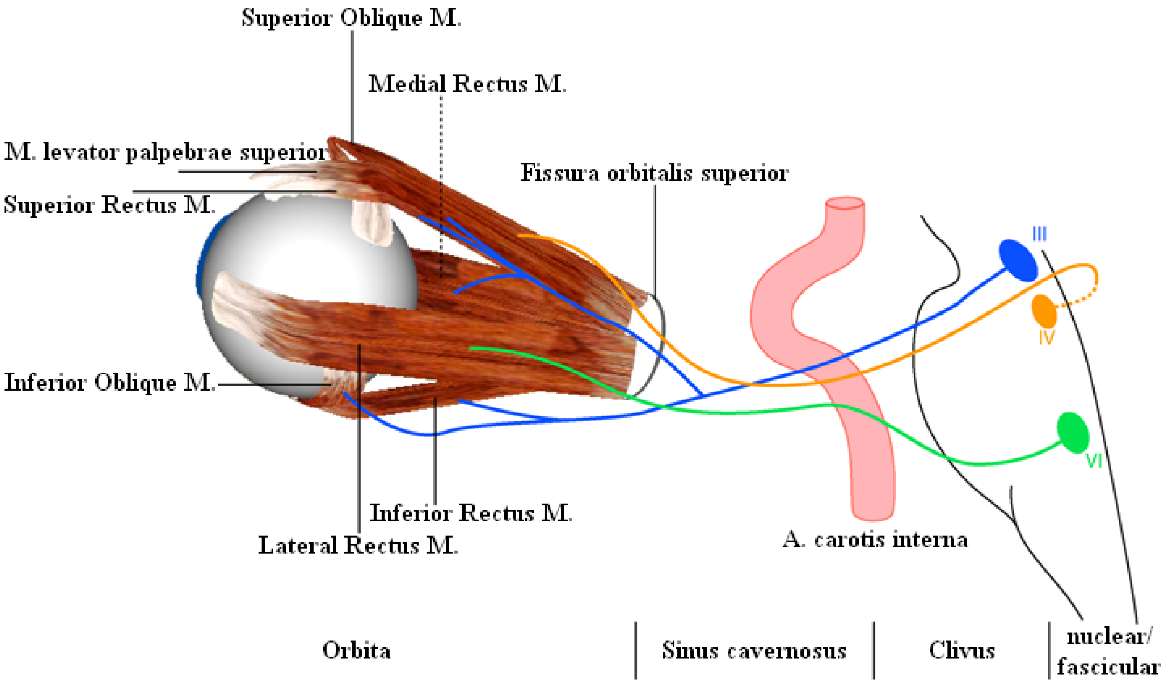
2. it concentrates the activities of those motor units, which have been active before but were not working with full capacity.

Motor Nuclei

The cell bodies of the motoneurons lie together in pairs and form the so-called nuclei within the brainstem. The nuclei area of the two oculomotoric nerves lies inside the midbrain. The alignment of those parts of the nuclei, which are associated with the specific eye muscles, is very complicated and most of the details have been examined as recently as in the last few years. The cell bodies of the medial rectus muscle, the inferior rectus muscle and the inferior oblique muscle lie ipsilaterally (i.e. for the right eye on the right nucleus-side). Only the cell bodies of the superior rectus muscle lie contralaterally (i.e. for the right eye on the left side of the III. nucleus pair). The nerve fibers of the superior rectus muscle cross in the area of the oculomoter nuclei to the other side. The cell bodies of the levator palpebrae muscle lie close to the middle line, both ipsilateral and contralateral.

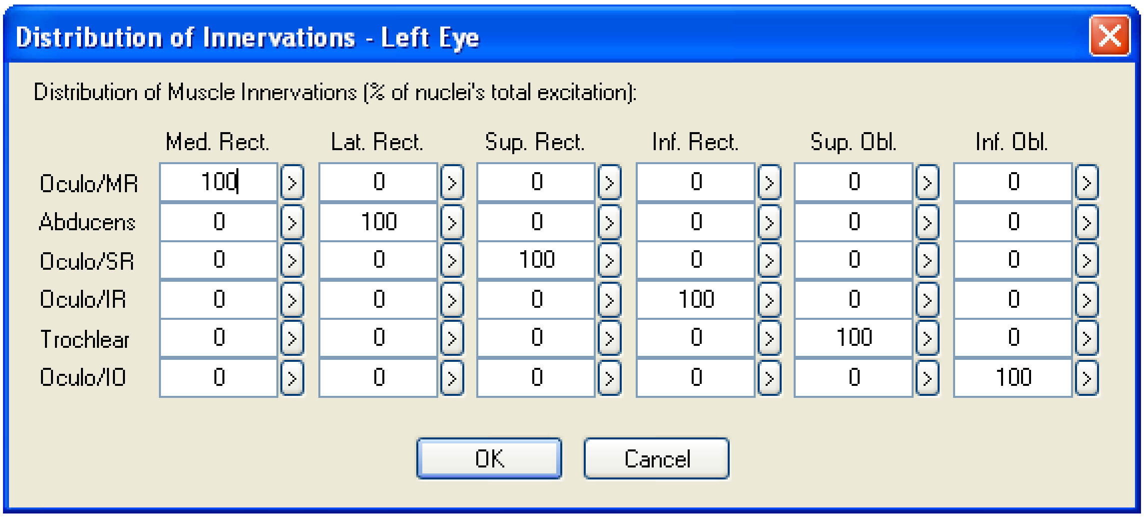
The two nuclei of the nervus trochlearis also lie in the midbrain just below the area of the oculomotor nuclei. The motoneurons of the nervus trochlearis originate contralaterally and cross behind the aqueduct, below the lamina quadrigemina, to the other side.

The nuclei of the nervus abducens lie in the bridge and are linked to the respective ipsilateral lateral rectus muscle.



Location of the Oculomotor Nuclei and Course of the Oculomotor Cranial Nerves

The SEE++ system does not contain its own simulation of the brainstem or the supranuclear structures. However, it realizes a so-called distribution of innervations for each eye, which makes it possible to change the percentage of innervation distributed from the oculomotor nuclei to the respective muscles. If such a distribution is modified, all innervations in relation to the affected muscle of the affected eye are scaled in percent.



Example of the Distribution of Innervations of the Left Eye (Based on Orbit™, See [Miller, 1999])

By modifying the distribution of innervations, it is possible to simulate either internuclear or supranuclear gaze palsies as well as, for example, retraction syndromes. A supranuclear gaze palsy when looking to the right would be simulated by changing the distribution of innervations of the nervus abducens to the lateral rectus muscle on the right eye and by changing the distribution of the nervus oculomotorius to the medial rectus muscle on the left eye. During a "simple" internuclear gaze palsy only one eye would be affected (saccades) and therefore only the distribution of innervations of one eye would require changes.

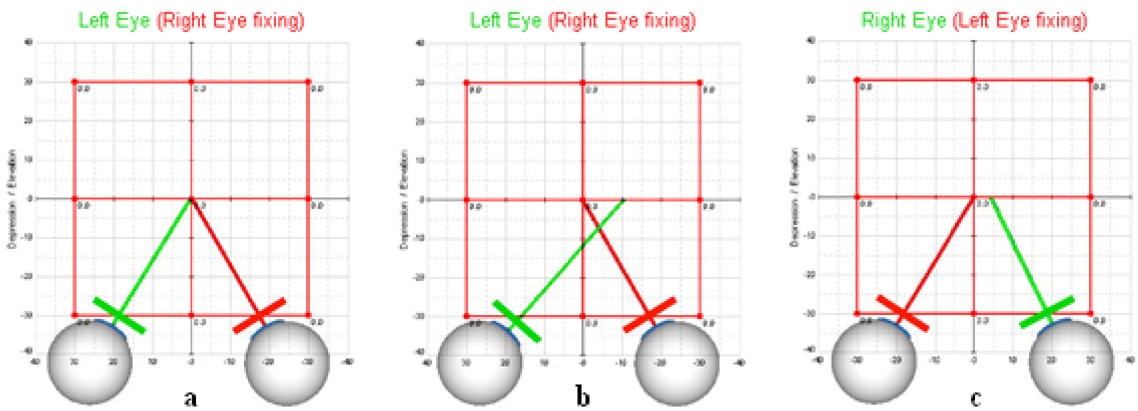
SEE++ uses a so-called invisible reference eye, which is used as basis for the calculations. If the distribution of innervations of this reference eye is changed, only the reciprocal following eye would reflect these changes in the Hess-Lancaster test. This allows for example the simulation of a lesion, which is only visible when observing the following eye.

2.3.2 Hess-Lancaster Test

The Hess-Lancaster test or Hess test is a test for binocular functions with separated images for both eyes. This clinical test is simulated by SEE++ with a "virtual patient" in order to enable comparison with real patient-measured data.

During the clinical Hess test the following steps are carried out:

1. The patient wears red-green-glasses with the red filter initially in front of the e.g. right eye (fixing eye).
2. The patient holds a green light pointer, the examiner holds a red light pointer.
3. The examiner projects a red light spot onto the so-called Hess screen and asks the patient to bring the green light spot (following eye) over the red light spot. Under normal conditions, both light spots overlay in all nine main gaze directions (see figure a).
4. Now the red filter is put in front of the other eye and the previous steps are repeated with the other eye, which is now the fixing eye.

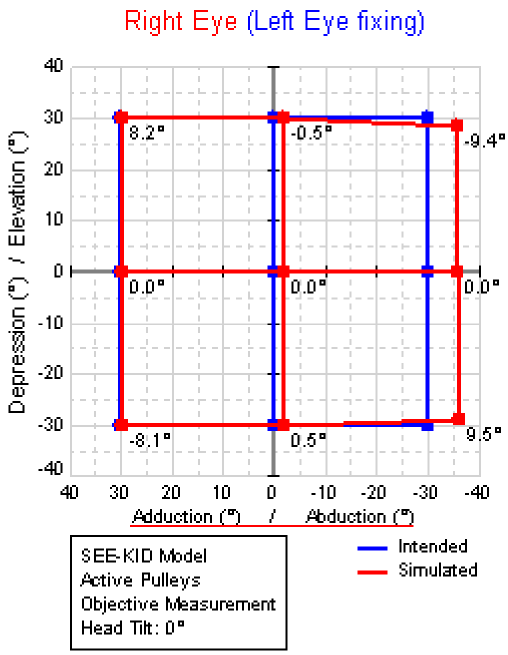


Possible Reactions of the Patient During the Hess Test

If the patient now fixates with the "normal" left eye, the fixation can be reached with "normal" innervation. However, if, for example, the right medial rectus muscle is paretic, then the patient's green light pointer will point at a spot that does not match with the correct direction (see figure c).

Another possible deviation occurs, if the patient for example has an abducens palsy on the right eye and is fixing with the same eye (red filter). Then the "normal" medial rectus muscle of the left eye receives an excessive innervation (Hering's law) and, as a consequence, the patient's green light pointer will point to a position on the screen, which lies far beyond the correct one (see figure b). After the test is finished, the relative positions are connected with straight lines.

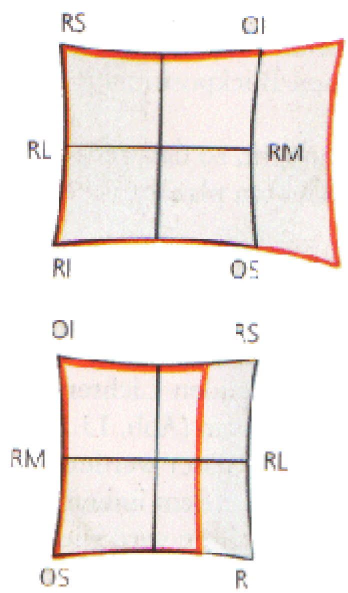
The results of the Hess test are normally two diagrams (left eye fixing and right eye fixing) with the corresponding gaze positions, which in turn show the deviation and the squint angle (see figure below).



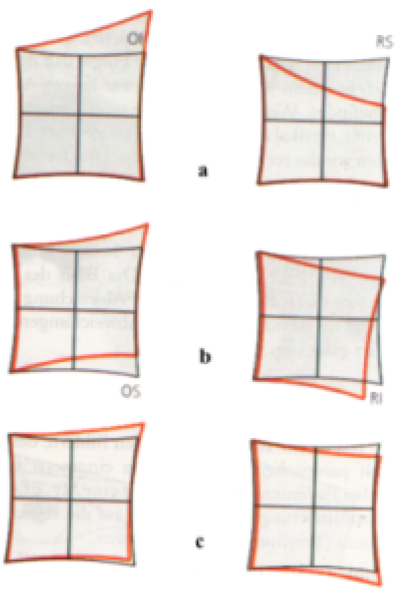
Example for a Left Eye Fixing During the Hess Test

In the Hess-diagram, the blue points represent those gaze positions which the patient should fixate (intended gaze positions) and the red points represent those gaze positions which the patient was able to reach with the following eye. The difference between the blue and the red points shows the respective deviation of the binocular coordination. At the same time, the torsion of the following eye is shown in textual form next to each red point (following gaze position). The following example gives an overview of the interpretation of Hess-diagrams for a medial rectus muscle paresis on the right eye:

1. The two diagrams (left eye fixing and right eye fixing) are compared.
2. The smaller diagram shows the eye with the paretic muscle.
3. The larger diagram corresponds to the eye with the overacting muscle.



4. The smaller diagram shows its biggest restriction in the main functional direction of the paretic muscle (in the figure this corresponds to the medial rectus muscle of the right eye).
5. The larger diagram shows its biggest expansion in the main functional direction of the synergistic muscle (in the figure this corresponds to the lateral rectus muscle of the left eye).



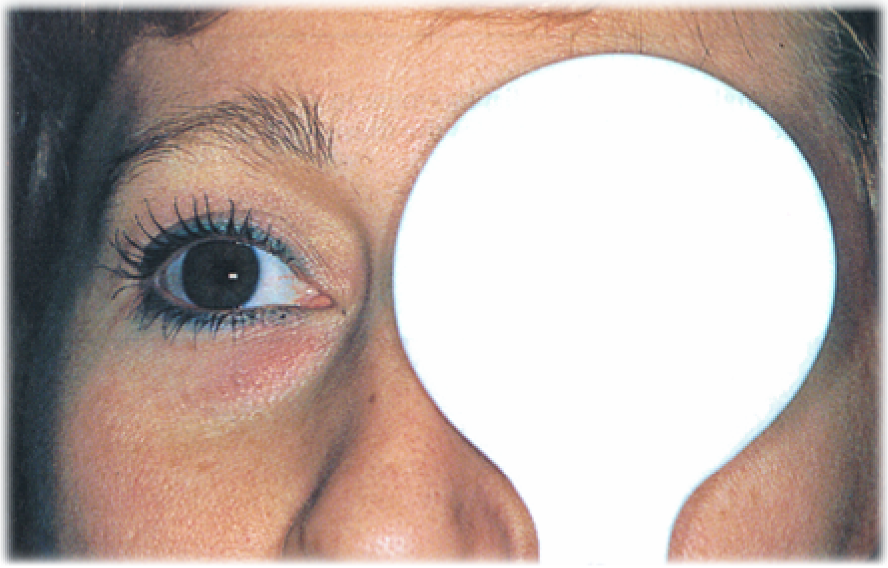
Changes in the Hess-diagrams are a prognostic help. For example, a paresis of the superior rectus muscle of the right eye will show a restriction of the affected muscle and a hyperfunction of the synergist (inferior oblique muscle of the left eye) (see figure a). As a result of this significant incomitant reaction shown in both diagrams, the diagnosis can be made directly out of the diagrams. But when the paretic muscle has recovered, both diagrams show approximately normal values again. If however the paresis persists, the shapes of both diagrams change and a secondary contracture of the ipsilateral antagonist (inferior rectus muscle of the right eye) develops, which can be seen as a hyperfunction in the diagram.

This in turn can lead to a secondary (inhibition) palsy of the superior oblique muscle of the left eye, which becomes apparent as a reduced action in the diagram (see figure b) and which gives the false impression that the left superior oblique muscle is the real cause for the pathological situation. By-and-by the two diagrams get even more concomitant up to the point where it is impossible to determine which muscle was the primary paretic muscle (see figure c).

The SEE++ system does not provide a simulation of convalescence processes or healing progresses. Nevertheless, it offers the possibility to save the data of such processes, just as surgeries, in form of scenarios and makes it possible to reproduce such changes in the form of carefully chosen parameters in the force model.

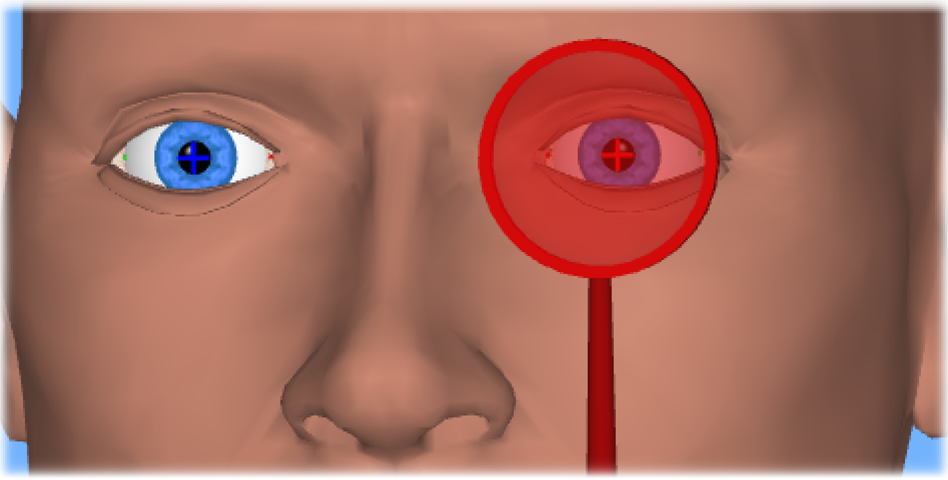
2.3.3 Cover Test

The cover test is used for the objective determination of type and extent of eye motility disorders by letting the patient fixate a nearby and a far away point while the eyes are intermittently or alternately covered with a blurred glass cover (or the hand) and by observing the fixation movements of the uncovered eye. With the cover test, horizontal and vertical deviations can be detected and measured. However, it is not applicable for measuring torsional deviations. Torsional movements can only be estimated by observing the rotation of globe vessels.



Covering the Left Eye with an Opaque Cover [Yanoff and Duker, 2003]

The first step when carrying out the cover test is to cover one eye and to observe and evaluate the movement of the uncovered eye. If a movement of the uncovered eye occurs in order to pick up fixation during the covering of the other eye, it has not participated in the fixation before, which means that in most cases it was squinting. With this examination method a manifest strabismus can be diagnosed. During the examination of both eyes, care should be taken to always uncover both eyes for a short period of time in order to allow fusion. Then the cover test can be carried out on the second eye. This is the so-called unilateral cover test.



Simulation of the Cover Test with SEE++

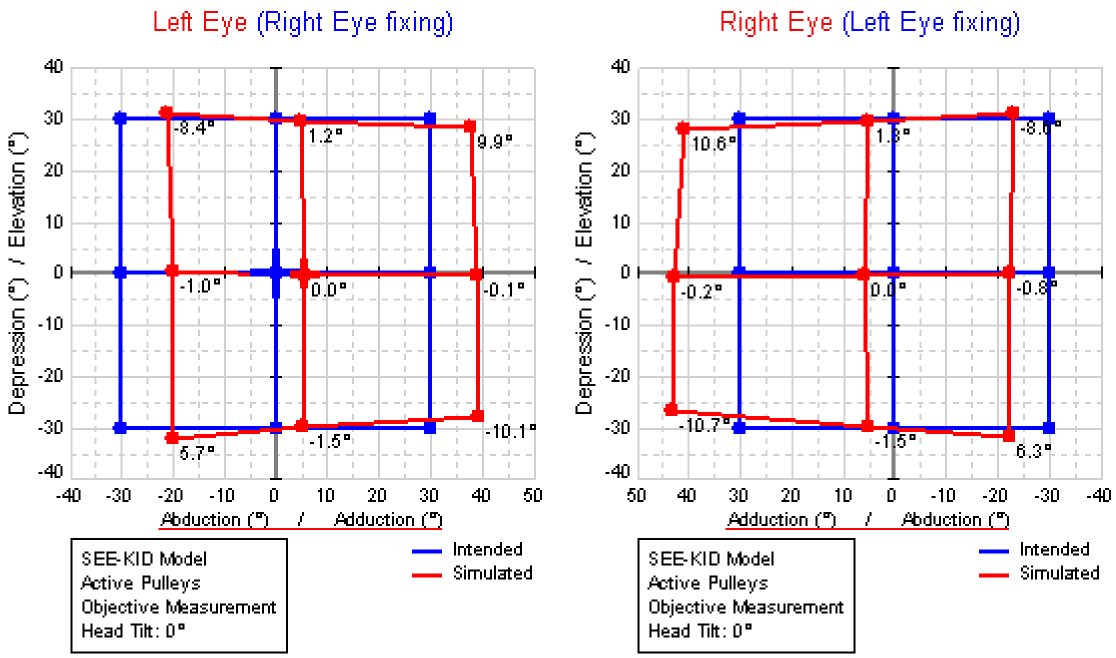
If no movement to pick up fixation can be observed during the unilateral cover test (central fixation is a prerequisite), the alternating cover test follows, where the cover is moved from one eye to the other eye (without an intermediate break). If now movements to pick up fixation can be observed, then a phorie (latent strabismus) exists. The diagnosis of a phorie is confirmed by the uncover test, where a previously covered eye is uncovered again. The movement of the uncovered eye is observed and if it performs a movement, a latent strabismus exists. Latent strabismus cannot be detected without covering.

SEE++ can simulate both the unilateral and the alternating cover test with the help of the biomechanical model. In addition, the simulation of manifest and latent strabismus is also possible, but the user has to specify the type of strabismus before the system can simulate it. Moreover, the preferred fixing eye can be chosen, which determines the eye that is set as the fixing eye by the SEE++ system after the cover has been removed from the covered eye or when no eye is covered.

2.3.4 Simulation

SEE++ uses a biomechanical model for simulating the binocular Hess-Lancaster test. The results of this test can be visualized in form of Hess-diagrams (left eye fixing and right eye fixing) and in form of a textual view (squint-angles diagram).

The main difference between the two visualizations is the declaration of the deviations. While the Hess-diagram offers a visual impression of a pathological situation and can be calculated for freely chosen gaze positions, the squint-angles diagram offers a textual illustration of the deviation values in the nine main gaze directions.



Left Eye (Right Eye fixing)

HD	VD	HD	VD	HD	VD
8.9	-1.4	4.9	0.1	7.6	1.4
EX 8.4 (PR -0.6)		IN 1.2 (PR -0.5)		IN 9.9 (PR -0.8)	
10.0	-0.5	5.7	0.1	8.9	0.3
EX 1.0 (PR -0.5)		EX 0.0 (PR -0.4)		EX 0.1 (PR -0.5)	
10.1	2.0	5.0	-0.1	9.2	-2.2
IN 5.7 (PR -0.7)		EX 1.5 (PR -0.5)		EX 10.1 (PR -0.8)	

Right Eye (Left Eye fixing)

HD	VD	HD	VD	HD	VD
10.7	-2.0	5.2	-0.1	6.8	1.1
IN 10.6 (PR -0.8)		IN 1.3 (PR -0.5)		EX 8.6 (PR -0.6)	
12.9	-0.4	6.0	-0.1	7.7	0.3
EX 0.2 (PR -0.6)		EX 0.0 (PR -0.4)		EX 0.8 (PR -0.5)	
13.3	3.4	5.2	0.1	7.8	-1.6
EX 10.7 (PR -0.8)		EX 1.5 (PR -0.5)		IN 6.3 (PR -0.7)	

SEE-KID Active Pulley Model - Objective Measurement - Head Tilt: 0° - HD / VD in Degrees

Hess-Diagrams and Squint-Angles Diagram (Right Eye Fixing and Left Eye Fixing)

In the squint-angles diagram the particular deviations for each gaze direction for right eye fixing and left eye fixing are entered, whereby HD denotes horizontal deviation and VD denotes vertical deviation. In the white fields of the diagram the torsional deviation as excyclotorsion or incyclotorsion (EX or IN) and the protrusion in mm (PR; negative protrusion = retraction) are specified. All values apart from the protrusion are in degrees. For HD and VD the user can select whether the values should be specified in degrees or prism diopters (PD).

The signs for the horizontal deviations are defined as follows:

- +HD: Towards the nose (adduction)
- -HD: Away from the nose (abduction)

The signs for the vertical deviations are defined differently for right eye and left eye fixing:

Right Eye Fixing

- +VD: Downward deviation of the left eye (depression)
- -VD: Upward deviation of the left eye (elevation)

Left Eye Fixing

- **+**VD: Upward deviation of the right eye (elevation)
- **-**VD: Downward deviation of the right eye (depression)

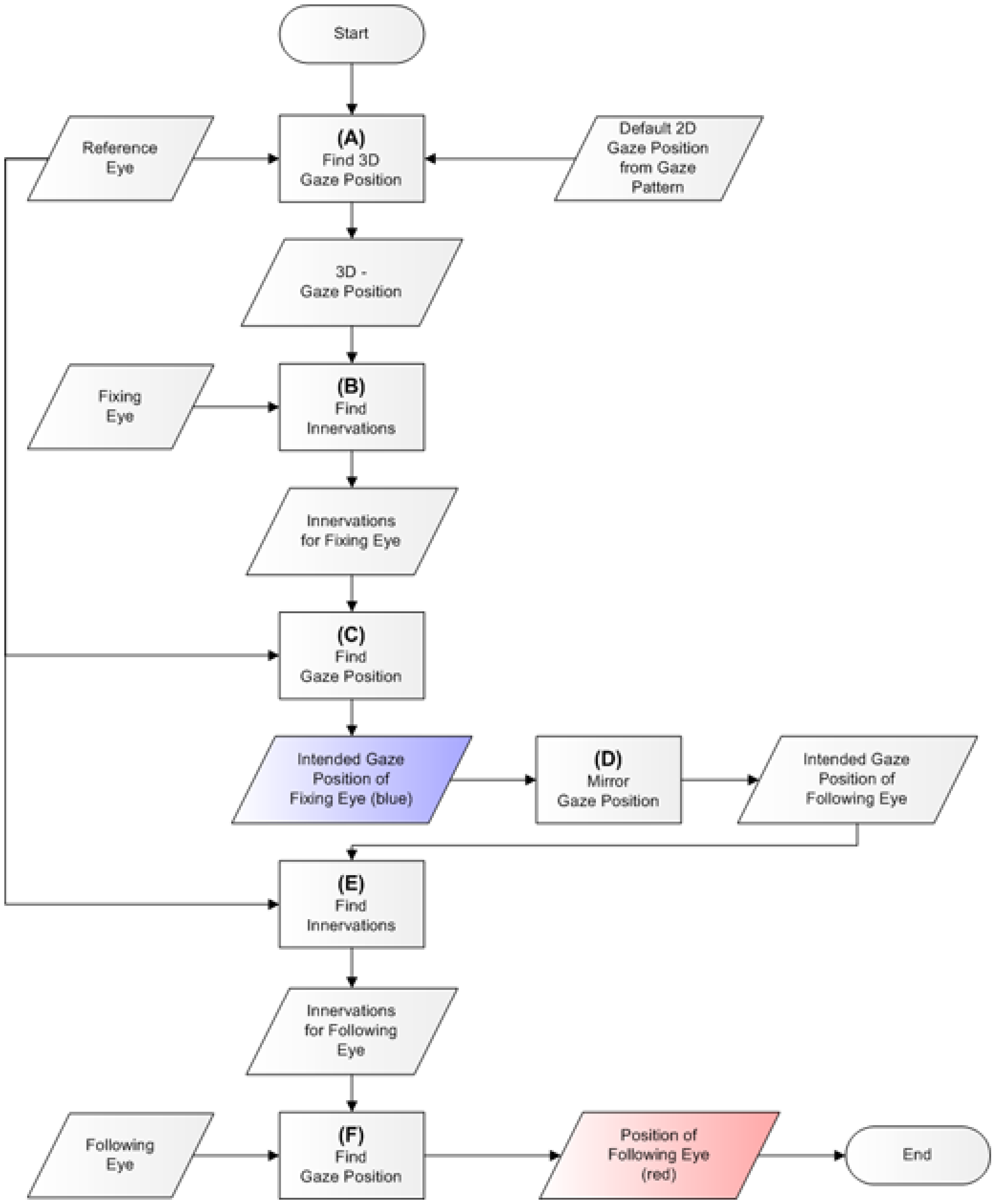
Different Types of Torsion (Cyclorotation)

The torsion values shown in the Hess-diagrams and the squint-angles diagram of SEE++ depend on the type of torsion measurement chosen in the program. By default, the torsion values in the diagrams correspond to clinical patient data resulting from an objective measurement. In this case objective measurement refers to a measurement, where the eye position including the torsion is directly measured on the patient (e.g. with a VOG (video oculography) system or with search coils) without the need for any information provided by the patient. If one now switches to subjective torsion measurement in SEE++, then the torsion values correspond to measurement values stated by the patient during a subjective test (e.g. tangent screen, Harms' wall). These torsion values correspond to the difference the patient perceives between one and the other eye (cyclo-deviation), since the "normal" torsion according to Listing's law (e.g. 8.2 degrees when looking 30 degrees in adduction and 30 degrees in elevation) also exists in a healthy eye (see Listing's law 27) and is not subjectively perceived by the patient. In order to be able to compare clinically measured torsion values with simulated torsion values, the appropriate torsion measurement has to be selected in the program.

In addition to Listing's torsion, SEE++ also calculates the counter roll, which occurs during the head tilt towards the left or right shoulder (VOR - vestibulo ocular reflex). For this purpose, the appropriate counter roll is calculated based on the current head tilt of the "virtual" patient and is combined with Listing's torsion or the current cyclo-deviation (depending on the selected torsion measurement). The combined torsion is then displayed in the different diagrams. Moreover, the Stateviewer offers the possibility to examine the separate components of which the combined torsion shown in the diagrams consists.

Simulation Task Flow

Sometimes it may be helpful to know how the internal simulation task flow of SEE++ works in order to interpret a simulation result. The following figure shows the schematic simulation task flow for the Hess-Lancaster test, which SEE++ performs for each gaze position of the fixing eye gaze pattern.



Simulation Task Flow for the Hess-Lancaster Test (Based on Orbit™, See [Miller, 1999])

The goal is to calculate the deviations of the following eye from the fixation positions of the fixing eye. Thereby, the fixing and following eye can be exchanged, i.e. either the right eye is fixing and the left eye is following or the left eye is fixing and the right eye is following. This makes it possible to calculate the Hess-diagram for right eye fixing and left eye fixing.

(A) Starting from a healthy reference eye and a given fixation position, a complete 3D eye position is calculated.
When providing a fixation position, of course only abduction/adduction and elevation/depression can be specified. The specification of a torsion is not possible, since a patient cannot explicitly rotate the eye around a specified torsional angle. As a result, the complete position of the fixing eye has to be calculated by generating innervations for eye

positions with Listing torsions with the help of the reference eye until the position of the fixing eye matches with these innervations and the desired 2D eye position.

(B) The innervation pattern for all six eye muscles is calculated for the determined 3D eye position with the fixing eye, which is necessary to bring the fixing eye into the desired position.

(C) These innervations are now put into the reference eye in order to calculate its eye position. If the fixing eye is pathological, the eye position calculated with the reference eye differs from the previously calculated eye position. The result of this calculation is now the actually intended fixation position of the fixing eye.

(D) In this step, the intended fixation position of the fixing eye is mirrored in order to get the intended position of the following eye. Since innervations cannot be mirrored (the contralateral synergist of the right lateral rectus muscle is the left medial rectus muscle which may not act in exactly the same way), this "indirection" of mirroring the eye position is necessary. The mirroring of an eye position is possible, because abduction/adduction and torsion of the two eyes have different signs for describing the same direction.

(E) Now the innervations of the reference eye are determined from the mirrored eye position so that the position of the following eye can be calculated afterwards.

(F) The innervations of the reference eye are now used to calculate the position of the following eye. This position is one of the red points in the Hess-diagram.

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Part III

3 Examples

This section contains three different examples which were modeled with SEE++:

1. Abducens palsy - as an example of an unilateral muscle palsy of a straight eye muscle
2. Superior oblique palsy - as an example of a palsy of an oblique muscle
3. Supranuclear gaze palsy - as a demonstration of a gaze palsy due to innervational causes

These examples offer an introduction to the system and the reader should be able to understand them without knowing the program in detail.

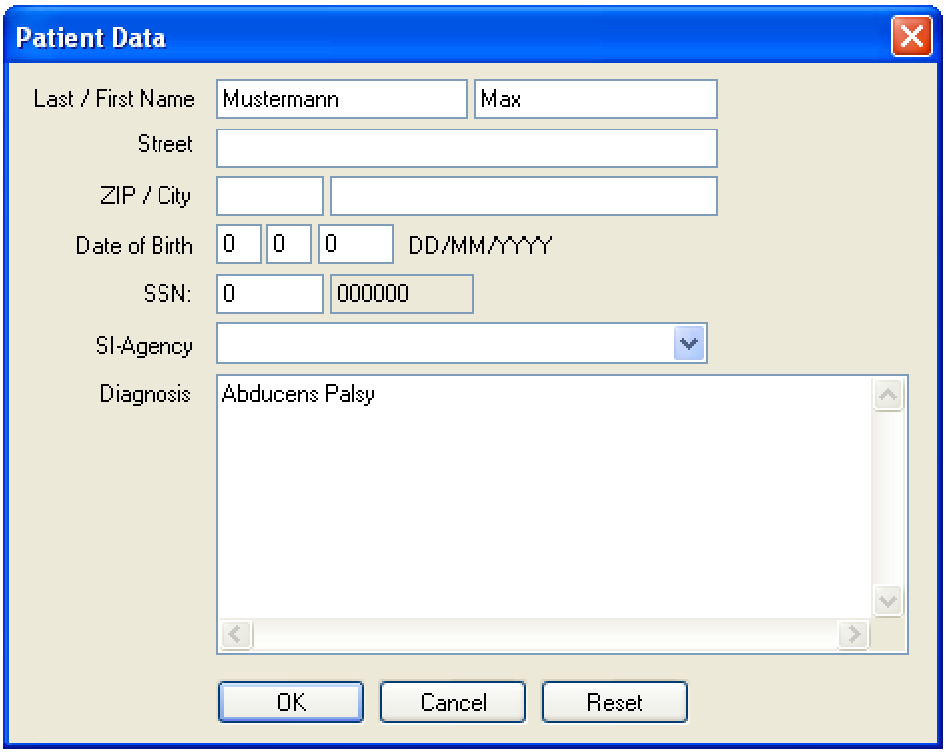
3.1 Abducens Palsy

In the first example, an abducens palsy of the right eye is simulated. The abducens palsy is an incomitant form of strabismus, i.e. the squint angle increases in the main functional direction (towards abduction in this pathology) of the affected muscle - the lateral rectus muscle. Clinically, the patient increasingly shows double images (uncrossed) towards abduction, thus when looking to the right. Possible causes for an abducens palsy are, among other things, traumata of the peripheral nerves (that is the entire nerve without the nucleus) caused for example by a basal skull fracture. As a result, a damage to the nerve somewhere from the nucleus (in the brainstem) up to the insertion can occur. In case of a damage directly within the area of the nucleus, it is possible that also the nearby interneurons (the connections between the nucleus of the nervus abducens and the conjugated muscle on the other side → medial rectus muscle) are hurt. This case is not assumed in this example.

Simulation of the Pathology

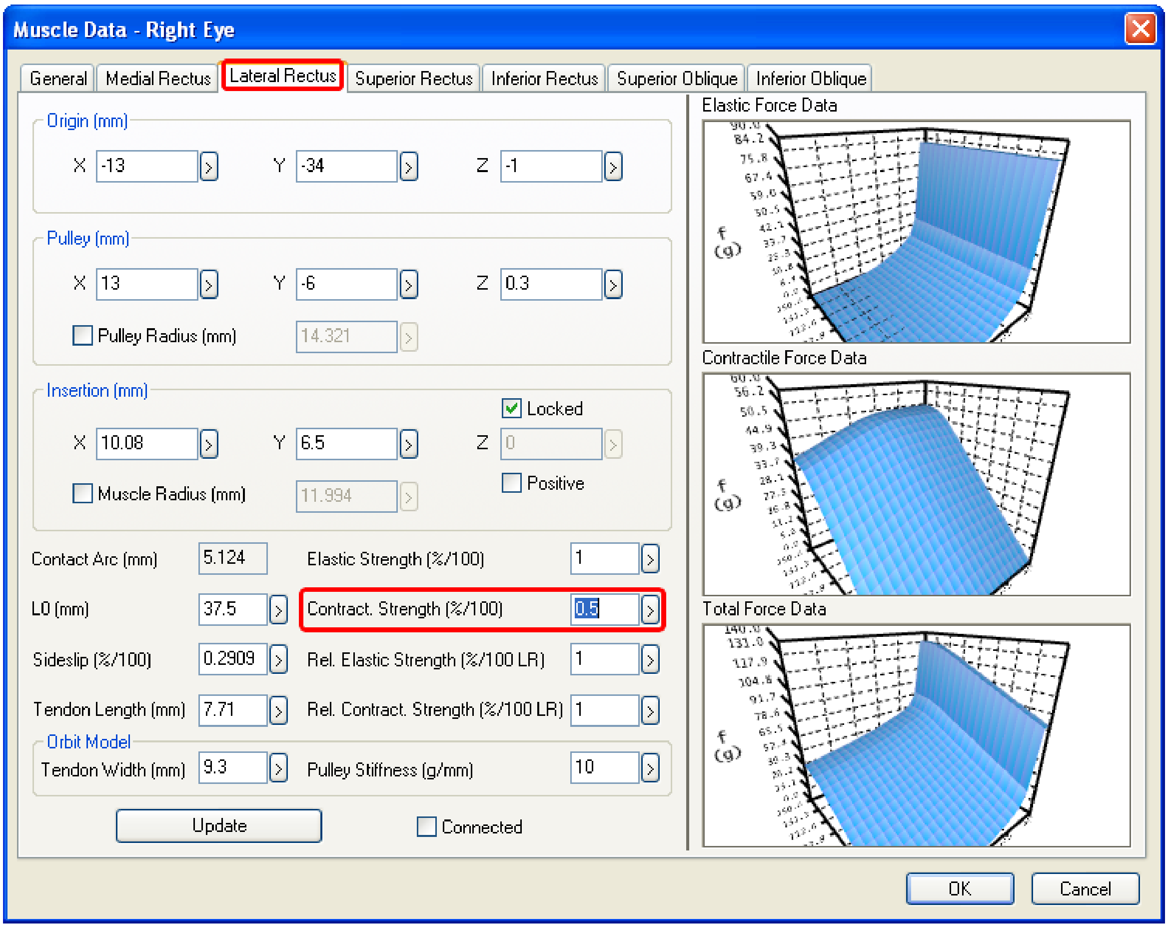
As a consequence of the damage to the nerve, the contractile strength of the muscle has to be reduced. This is the basis for the simulation.

First a new patient is created. To do so, the menu item *"Patient"* - *"New Patient"* is used, which displays the following dialog:



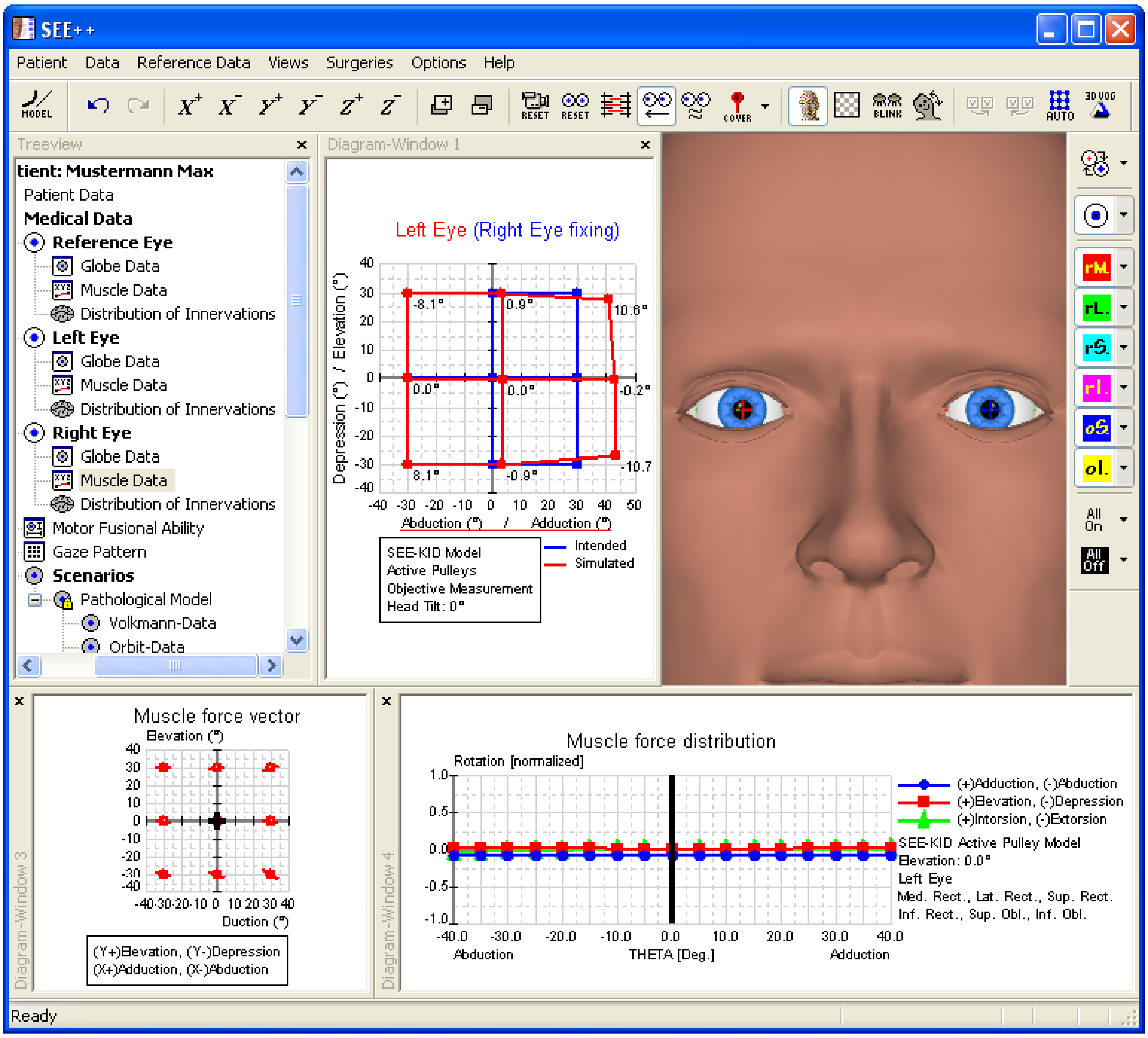
In this dialog, information about the patient can be entered. After clicking on the "OK" button, the new patient is created and the program is ready for starting with the simulation.

In order to successfully simulate the abducens palsy, the contractile strength of the lateral rectus muscle of the right eye has to be reduced. In SEE++, this force reduction is carried out in the muscle data dialog, which is accessible either by the menu item *"Data"* - *"Right Eye"* - *"Muscles"* or by the tree in the left part of the program window by using the tree item "Muscle Data" in the section for the right eye. In the upper area of the appearing window there are several "tab sheets", namely one containing general parameters and one for each muscle. By clicking on the tab sheet "Lateral Rectus", the dialog now looks like this:

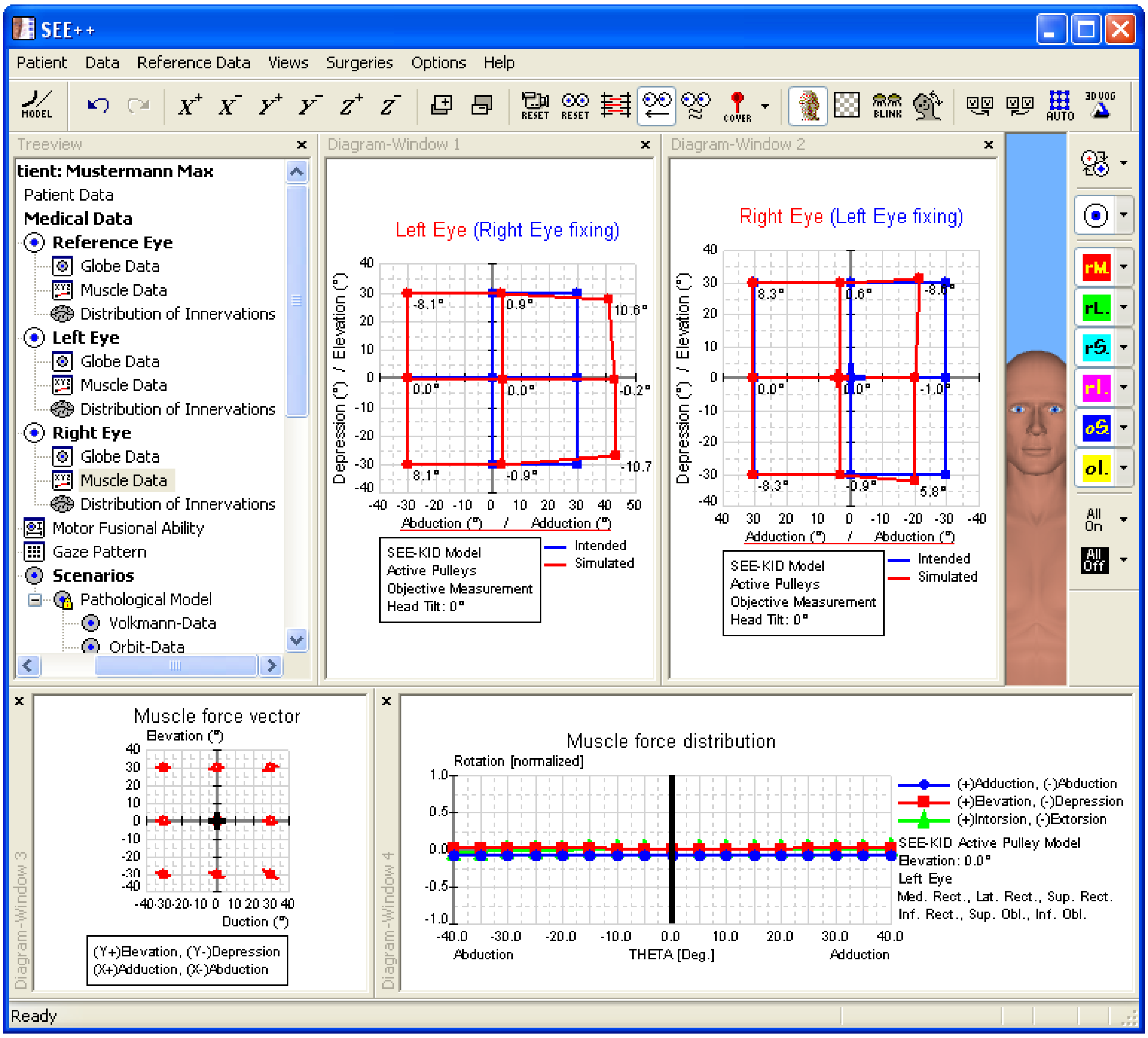


In the field "Contract. Strength" the strength of the muscle can be reduced by changing the value from 1 %/100 to **0.5 %/100** and afterwards closing the dialog by clicking on "OK".

When the Hess-diagram is recalculated now, the modifications from the muscle data dialog are immediately taken into account. By default, the Hess-diagram for the left eye (right eye fixing) is displayed in the diagram-window with the number 1. After the calculation of the Hess-diagram has been successfully finished, the following is displayed:



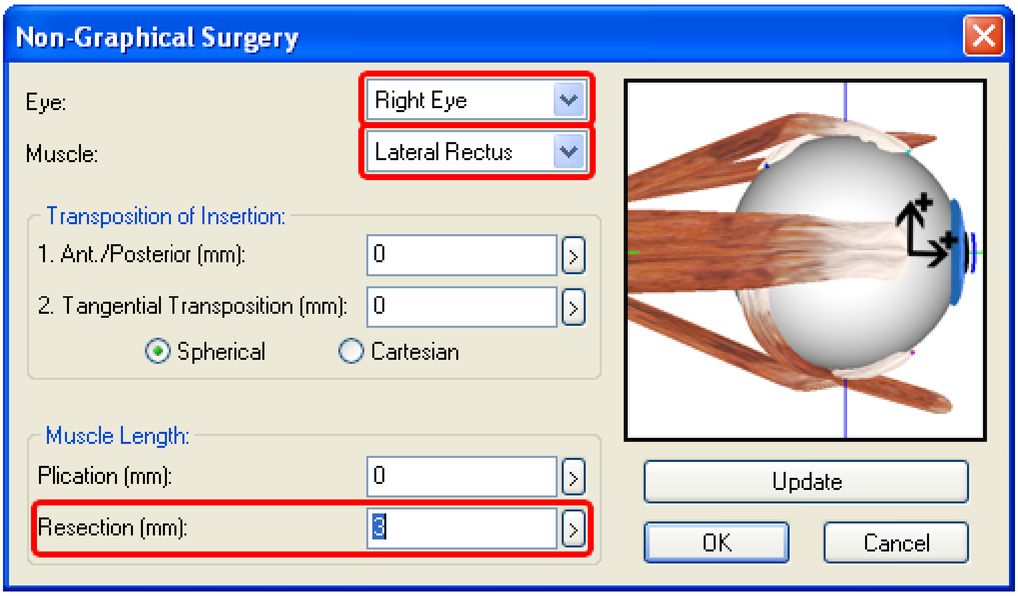
In the calculated Hess-diagram the exceeding reaction of the following left eye (right eye fixing) into adduction can be clearly seen. In order to display the second Hess-diagram for the right eye (left eye fixing), use the menu item *"Views" - "Diagram-Window 2"*. By default, the now displayed diagram-window with the number 2 displays the Hess-diagram for the right eye (left eye fixing). If this is not the case, you can simply click into one of the diagram-windows with the right mouse button and select the desired diagram in the displayed popup menu by left-clicking on it. If the size of the two diagram-windows is adjusted accordingly by clicking on the dividing line between the diagrams and resizing the diagrams with the left mouse button pressed, the following view is displayed:



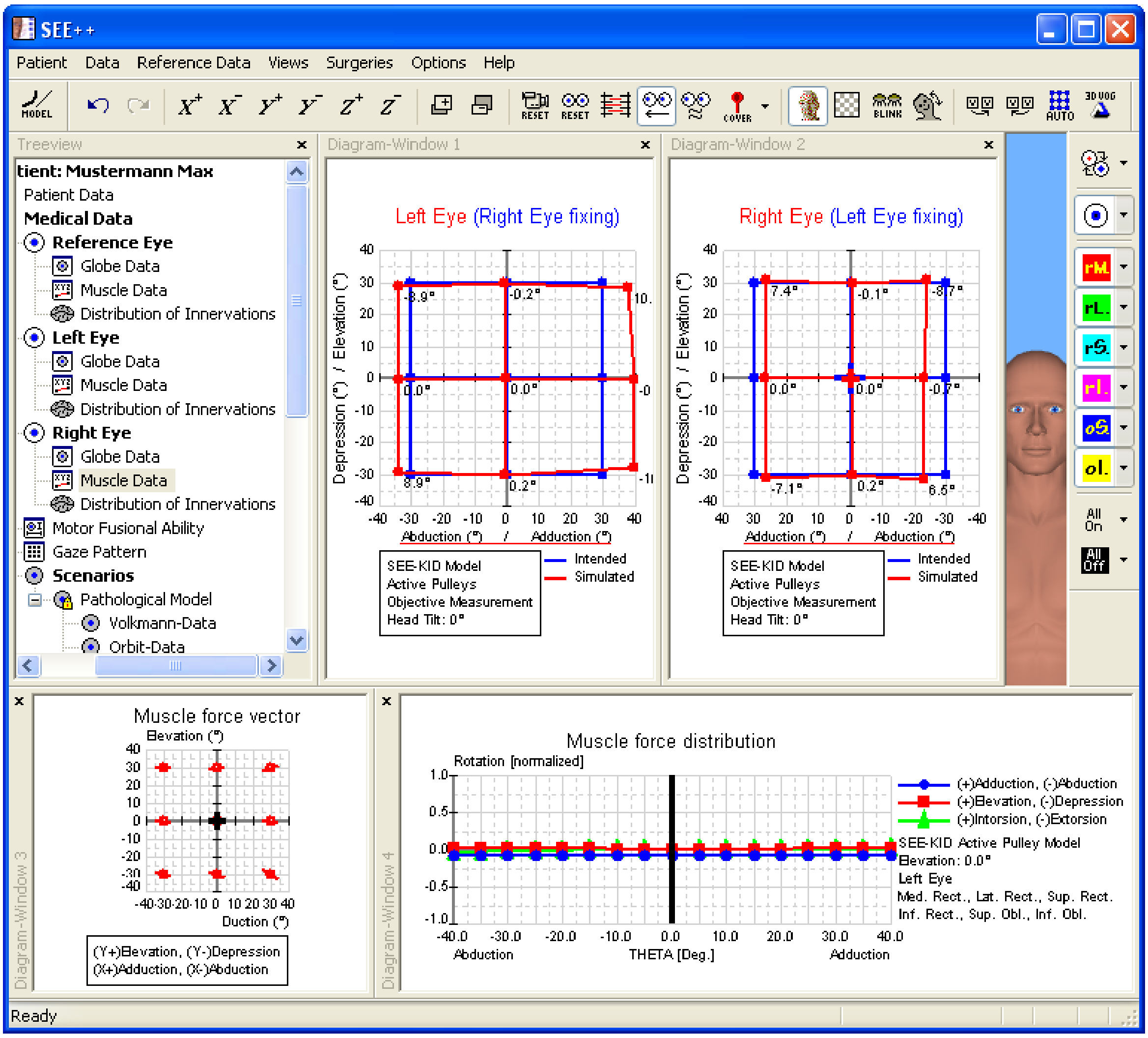
In the Hess-diagram for the right eye (left eye fixing) the restriction of the right eye in abduction can be clearly seen. On the basis of the results of the simulation, which are shown in the Hess-diagrams, the simulation of the abducens palsy can be considered as finished.

Surgical Correction

For the surgical correction of the simulated abducens palsy, a strengthening of the paretic muscle is necessary. The surgery is carried out by shortening (resection) the affected lateral rectus muscle. During a resection surgery, the insertion of a muscle is separated from the globe, a piece of the muscle is cut off and afterwards, the muscle is fixed again at the same position on the globe. For shortening a muscle in SEE++, the "Non-Graphical Surgery" dialog is used, which is accessible by the menu item *"Surgeries" - "Non-Graphical Surgery"*. After the dialog has been opened, the desired eye and the desired muscle are selected, in this case the right eye and the lateral rectus muscle. Now a resection of 3 mm of the selected muscle is carried out by entering the appropriate value in the field "Resection (mm)". The following picture shows the dialog with the entered resection value:



After closing the dialog with a click on the "OK" button, the program recalculates the two Hess-diagrams. When the calculation is finished, the following picture is displayed:



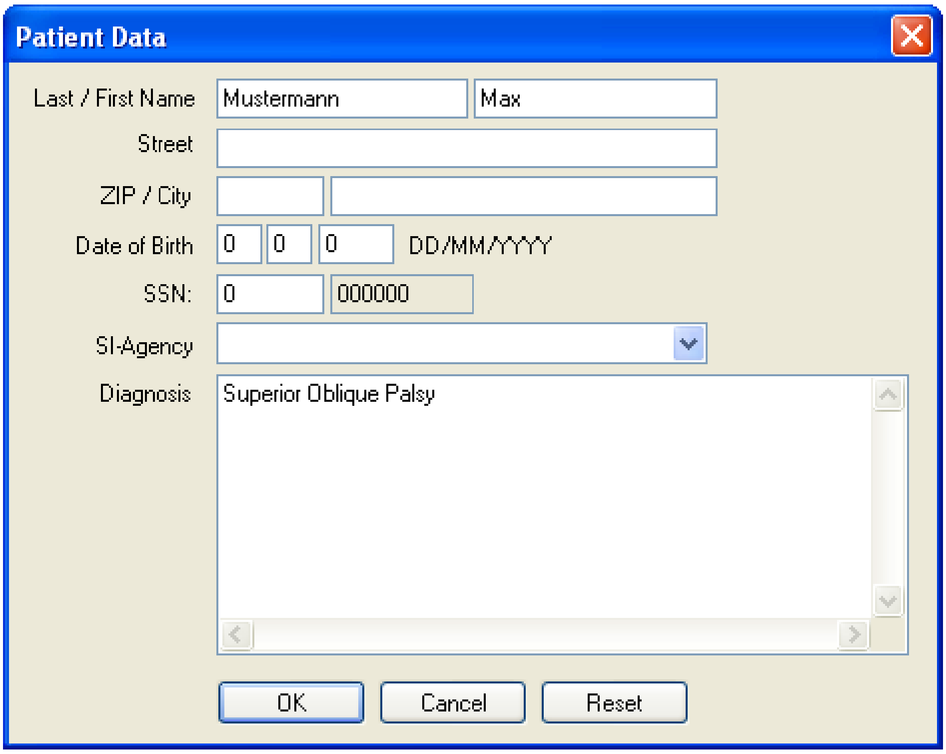
Now the two Hess-diagrams show that the goal of the surgical correction has been achieved, namely to get the double image free zone into the primary position without substantially weakening the adduction. However, a complete "healing" of the palsy by modifying the innervational component in the model is clinically not possible, since a surgical modification of the innervation is impossible.

3.2 Superior Oblique Palsy

In the second example, a superior oblique palsy of the right eye is simulated. This palsy is, similar to the abducens palsy, an incomitant squinting form, i.e. the squint angle increases in the main functional direction of the affected muscle. The vertical deviation increases accordingly towards adduction and depression, similarly the extorsion increases in abduction. The horizontal component is influenced in terms of a more or less convergent deviation (esophoria - esotropia, horizontal incomitance, A-pattern). Again, similar to the abducens palsy, a possible cause for the palsy can be a craniocerebral trauma. The long path of the nervus trochlearis is like the path of the nervus abducens very vulnerable for traumatic injuries. In clinical practice the patient normally adopts a forced posture of the head (head tilt to the left) for balancing the extorsion and for maintaining the binocular vision. Vertically shifted and outward-tilted double images increase in depression and convergence (main functional area of the muscle).

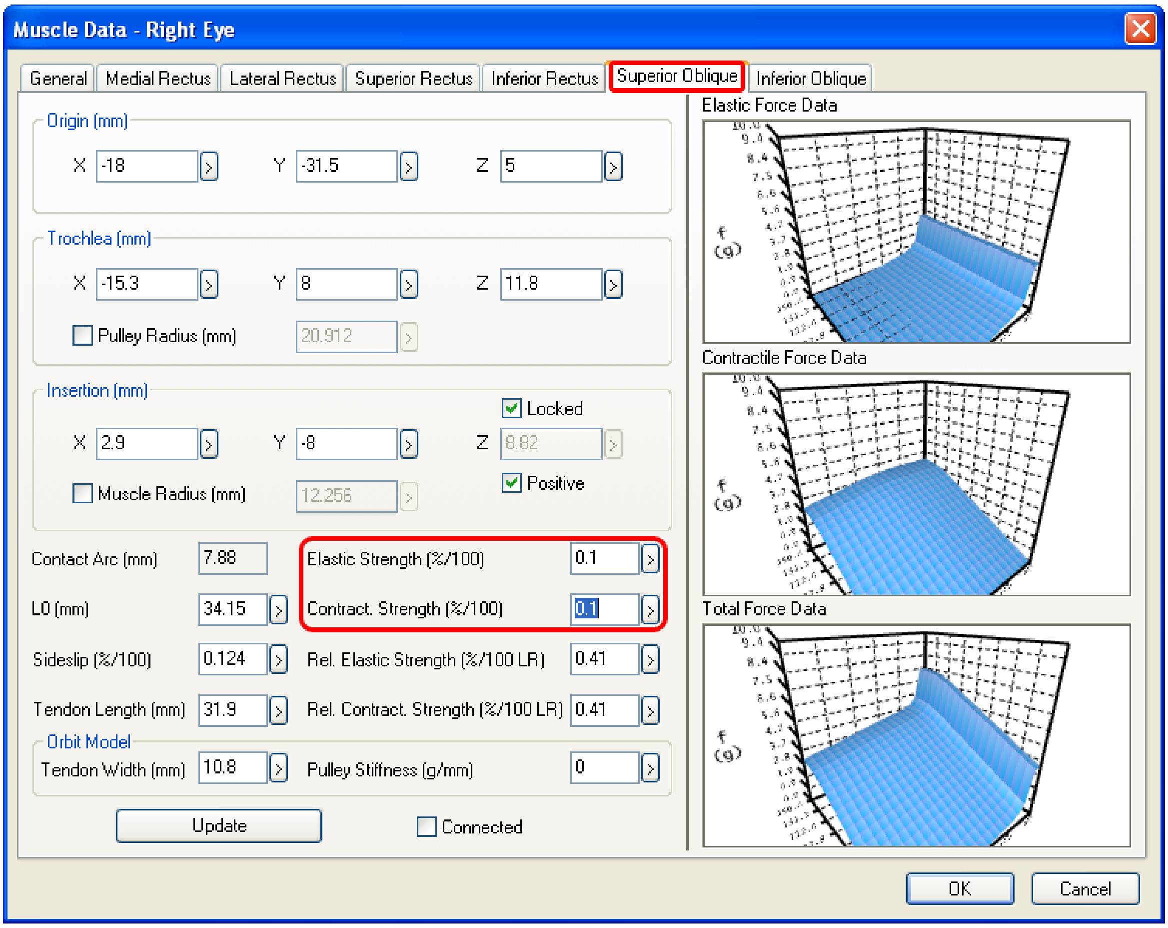
Simulation of the Pathology

Similar to the simulation of the already described abducens palsy 59, for a successful simulation of this pathology the contractile strength, as a consequence of the damage to the nerve, as well as the elastic strength have to be reduced. This is the basis for the simulation.
First a new patient is created. To do so, the menu item *"Patient"* - *"New Patient"* is used, which displays the following dialog:



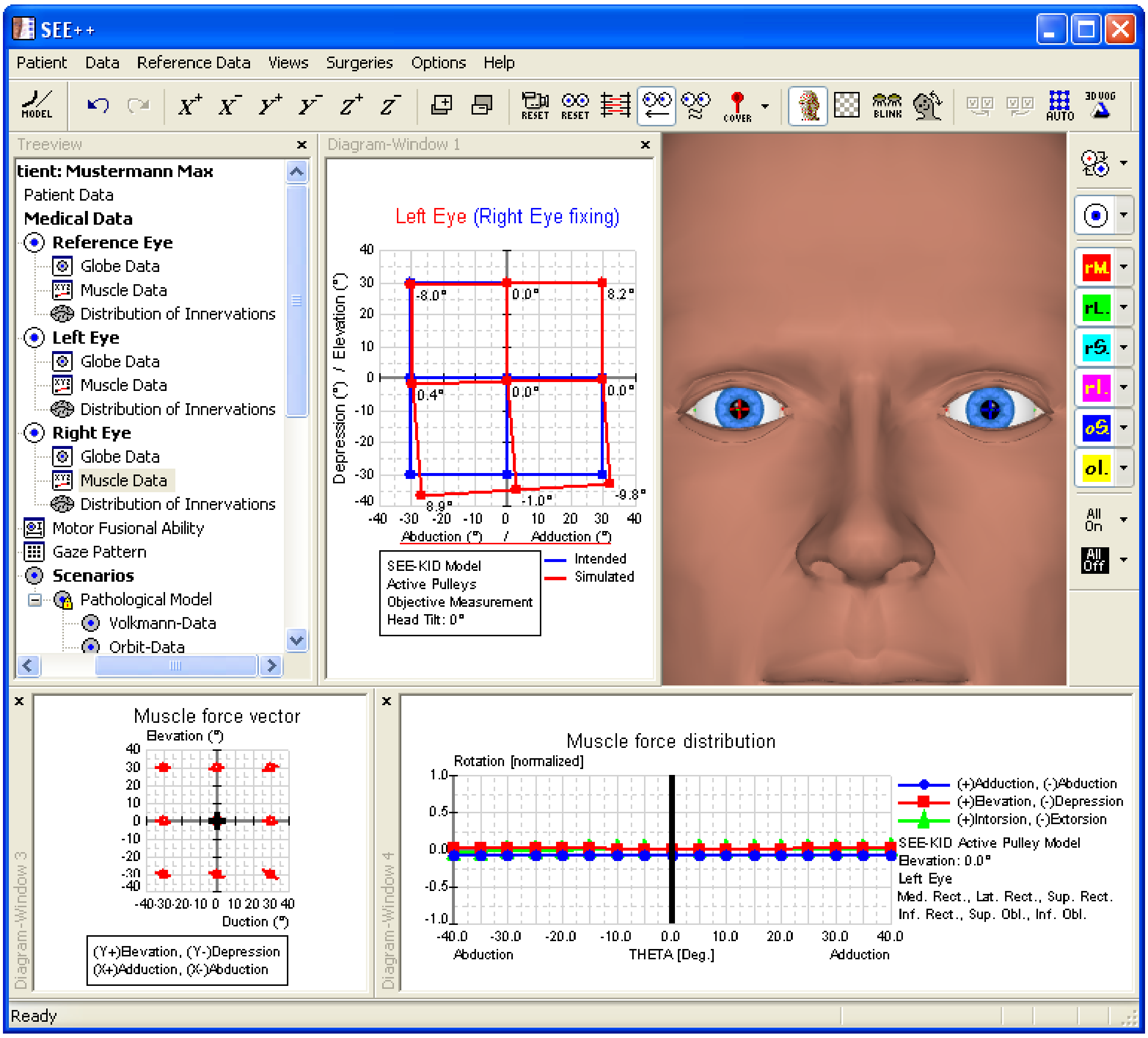
In this dialog, information about the patient can be entered. After clicking on the "OK" button, the new patient is created and the program is ready for starting with the simulation.
In order to successfully simulate the superior oblique palsy, the strength of the superior oblique muscle of the right eye has to be decreased. In SEE++, this force reduction is carried out in the muscle data dialog, which is accessible either by the menu item *"Data"* - *"Right Eye"* - *"Muscles"* or by the tree in the left part of the program window by using the tree item "Muscle

Data" in the section for the right eye. In the upper area of the appearing window there are several "tab sheets", namely one containing general parameters and one for each muscle. By clicking on the tab sheet "Superior Oblique", the dialog now looks like this:

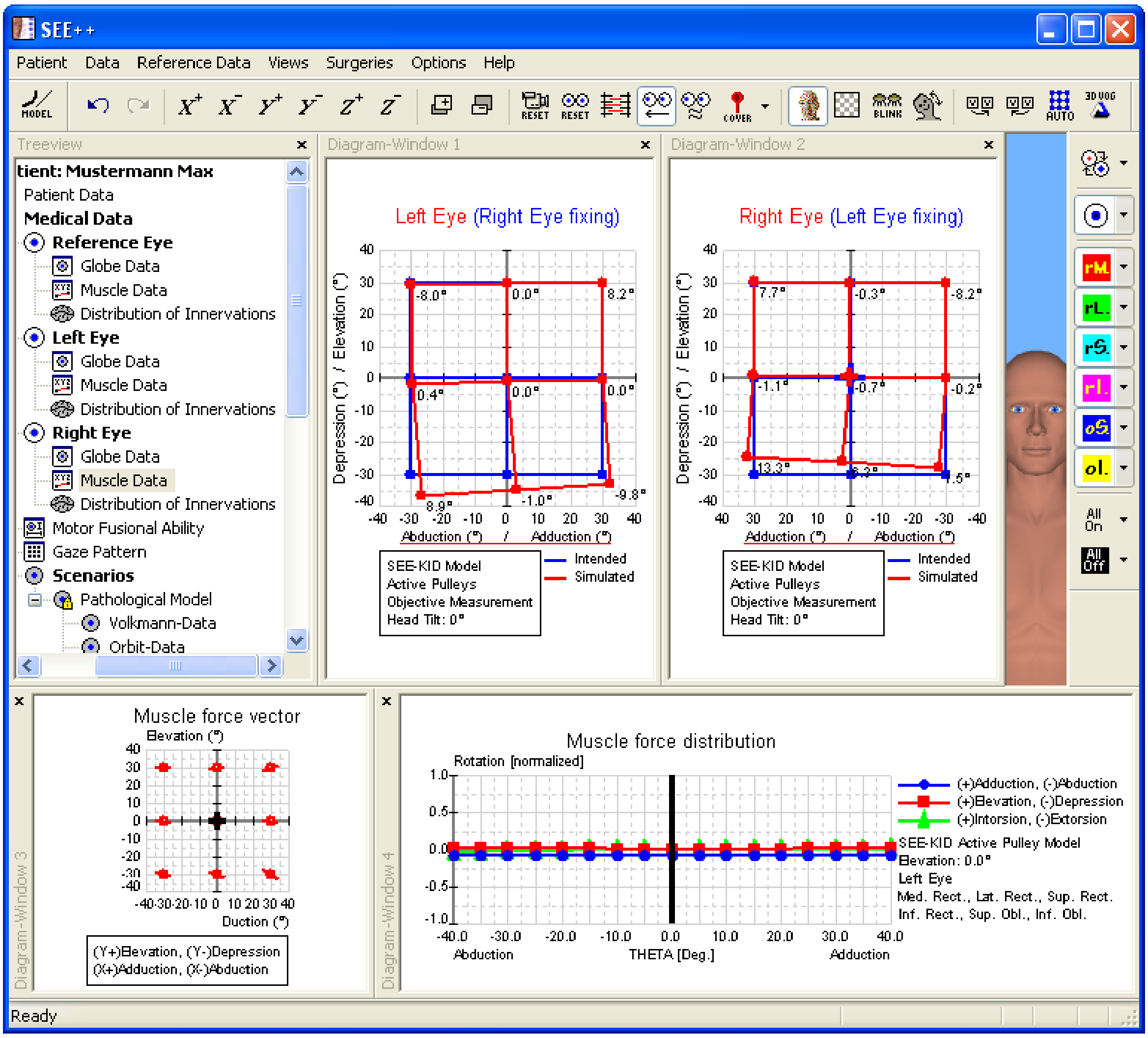


In the fields "Elastic Strength" and "Contract. Strength" the respective force components of the muscle can be reduced by changing both values from 1 %/100 to **0.1 %/100** and afterwards closing the dialog by clicking on "OK".

When the Hess-diagram is recalculated now, the modifications from the muscle data dialog are immediately taken into account. By default, the Hess-diagram for the left eye (right eye fixing) is displayed in the diagram-window with the number 1. After the calculation of the Hess-diagram has been successfully finished, the following is displayed:



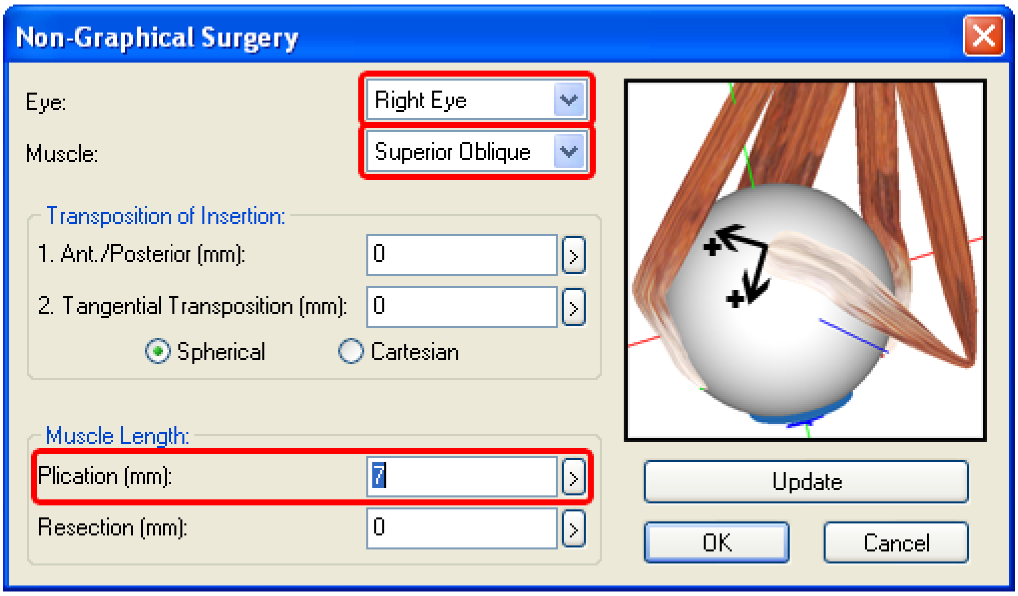
In the calculated Hess-diagram the exceeding reaction of the inferior rectus muscle of the following left eye (right eye fixing) can be clearly seen. In order to display the second Hess-diagram for the right eye (left eye fixing), use the menu item *"Views" - "Diagram-Window 2"*. By default, the now displayed diagram-window with the number 2 displays the Hess-diagram for the right eye (left eye fixing). If this is not the case, you can simply click into one of the diagram-windows with the right mouse button and select the desired diagram in the displayed popup menu by left-clicking on it. If the size of the two diagram-windows is adjusted accordingly by clicking on the dividing line between the diagrams and resizing the diagrams with the left mouse button pressed, the following view is displayed:



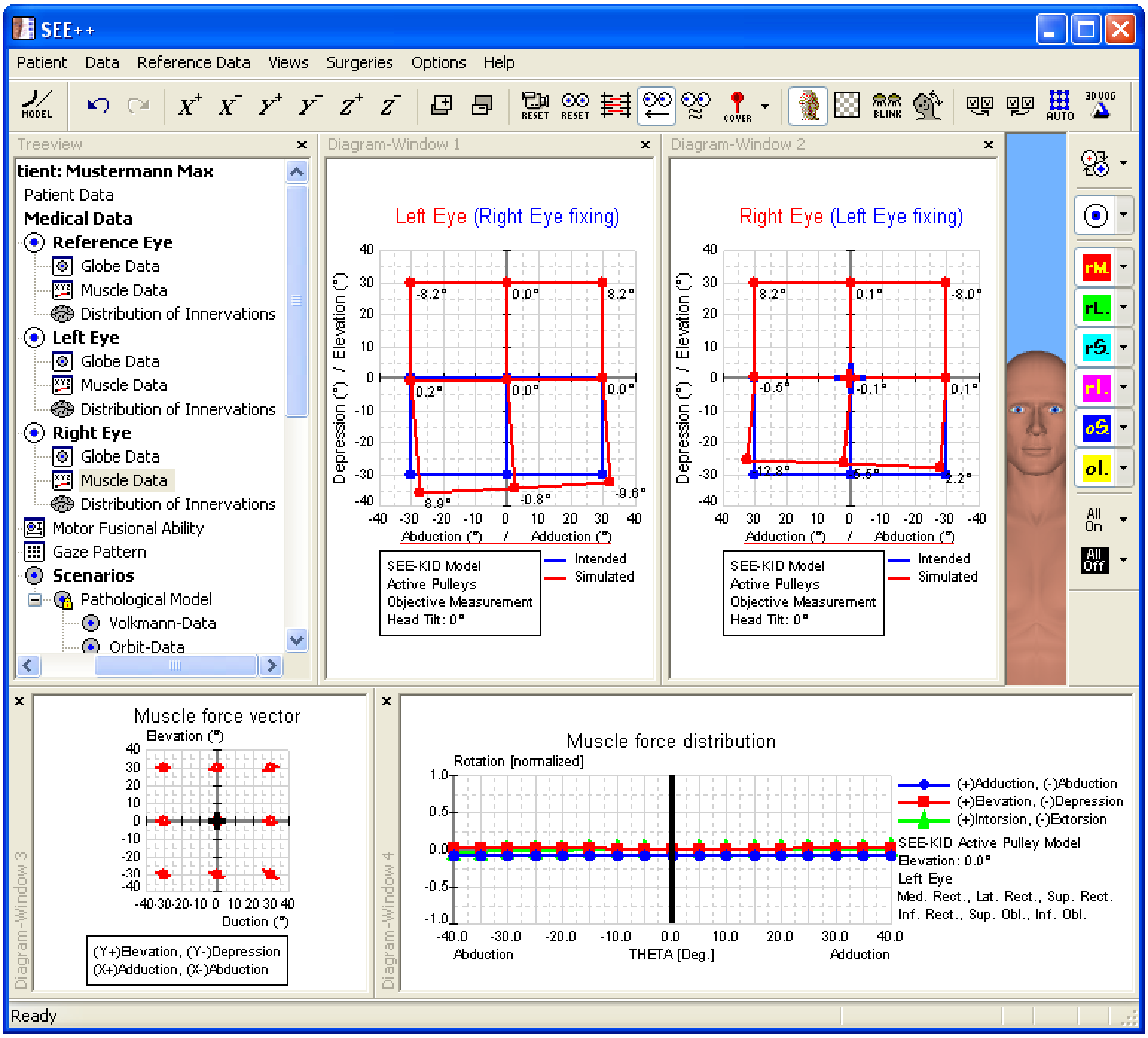
In the Hess-diagram for the right eye (left eye fixing) the increasing incomitant restriction of the superior oblique muscle of the right eye in adduction can be clearly seen. On the basis of the results of the simulation, which are shown in the Hess-diagrams, the simulation of the superior oblique palsy can be considered as finished.

Surgical Correction

For the surgical correction of the simulated superior oblique palsy, a strengthening of the paretic muscle is necessary. The surgery is carried out by a plication of the affected superior oblique muscle. In order to perform a plication surgery in SEE++, the "Non-Graphical Surgery" dialog is used, which is accessible by the menu item *"Surgeries" - "Non-Graphical Surgery"*. After the dialog has been opened, the desired eye and the desired muscle are selected, in this case the right eye and the superior oblique muscle. Now a plication of 7 mm of the selected muscle is carried out by entering the appropriate value in the field "Plication (mm)". The following picture shows the dialog with the entered plication value:



After closing the dialog with a click on the "OK" button, the program recalculates the two Hess-diagrams. When the calculation is finished, the following picture is displayed:



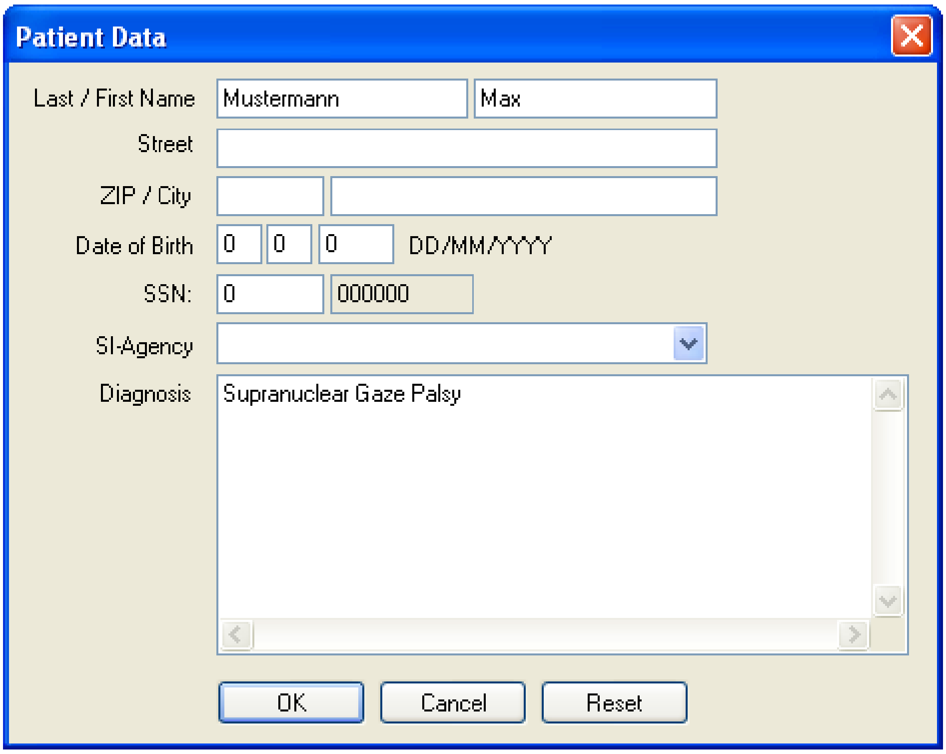
Now the two Hess-diagrams show that the target of the surgical correction has been achieved, namely to get the double image free zone into the primary position. Furthermore, the increasing incomitant restriction of the upper oblique muscle of the right eye in adduction and depression was slightly reduced by the plication. However, a complete "healing" of the palsy, specifically in extreme adduction and depression, by modifying the innervational component in the model is clinically not possible, since a surgical modification of the innervation is impossible.

3.3 Supranuclear Gaze Palsy

The third example describes a dexter supranuclear gaze palsy. The lesion for this simulation should be cortical (cerebral cortex) above the nuclei of the eye muscles (brainstem). In most cases, apoplectic strokes are the reason for such gaze palsies. Due to a local ischemia of the cerebral hemisphere, on the left side for a dexter gaze palsy, the impulses for moving the eyes to the opposite side (in this simulation to the right) are disordered.

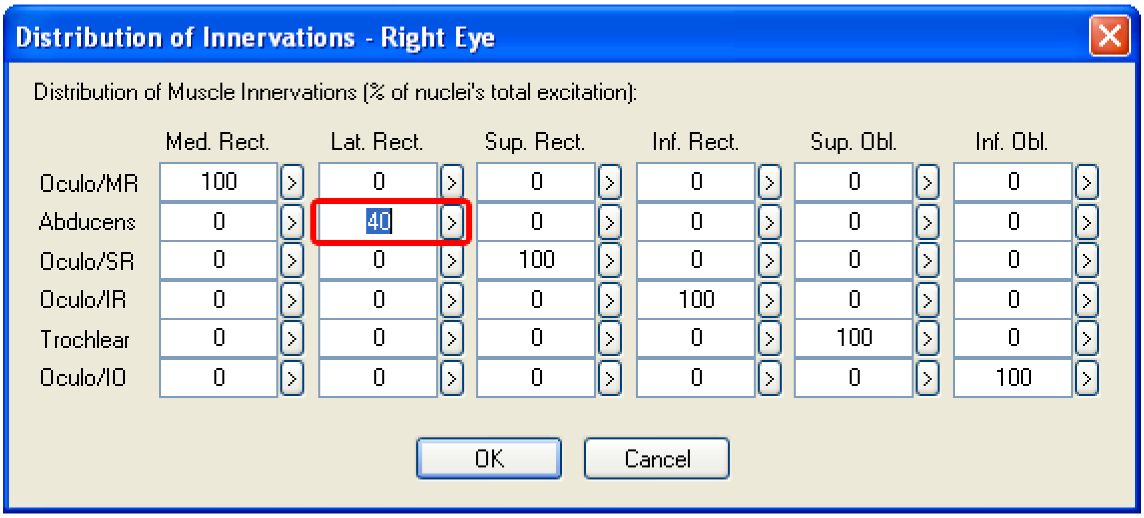
Simulation of the Pathology

During a supranuclear gaze palsy, the central nerve impulse to both eyes, in contrast to a lesion of the peripheral nerves like described in the previous examples, is affected. Therefore, the simulation of a supranuclear gaze palsy has to be carried out in SEE++ by modifying the distribution of innervations of both eyes.
First a new patient is created. To do so, the menu item *"Patient" - "New Patient"* is used, which displays the following dialog:

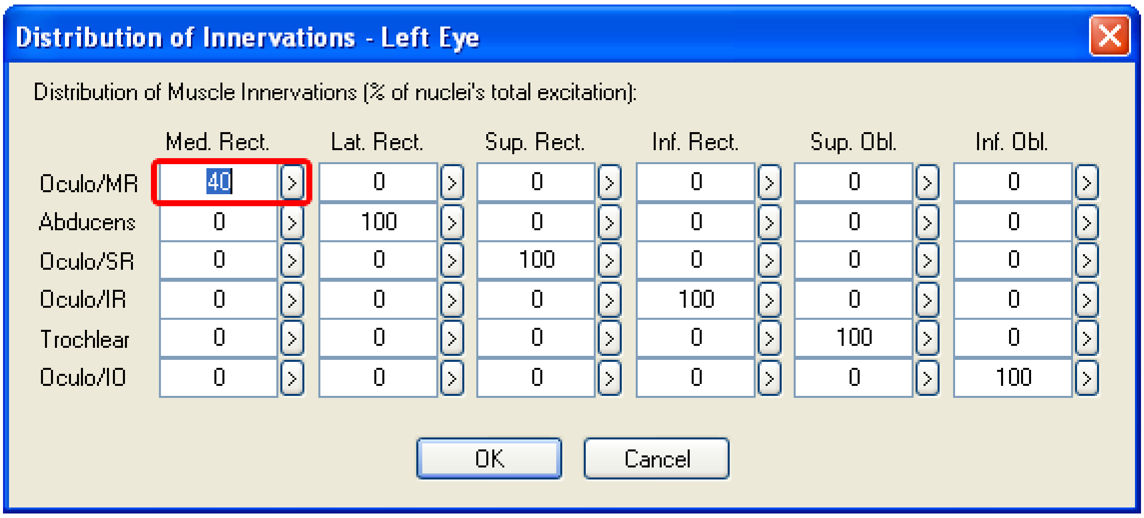


In this dialog, information about the patient can be entered. After clicking on the "OK" button, the new patient is created and the program is ready for starting with the simulation.
Since a dexter gaze palsy is to be simulated, the innervation of the lateral rectus muscle of the right eye has to be reduced to 40 % and at the same time the innervation of the medial rectus muscle of the left eye also has to be reduced to 40 %. In SEE++, each of these modifications can be carried out in the respective "Distribution of Innervations" dialog, which is accessible either by the menu item *"Data" - "Right Eye"* or *"Left Eye" - "Distribution of Innervations"* or by the tree in the left part of the program window by using the tree item "Distribution of Innervations" in the section for the right or left eye.
First, the innervation of the lateral rectus muscle (Abducens) of the right eye is changed by opening the "Distribution of Innervations" dialog as described above. In the dialog, the

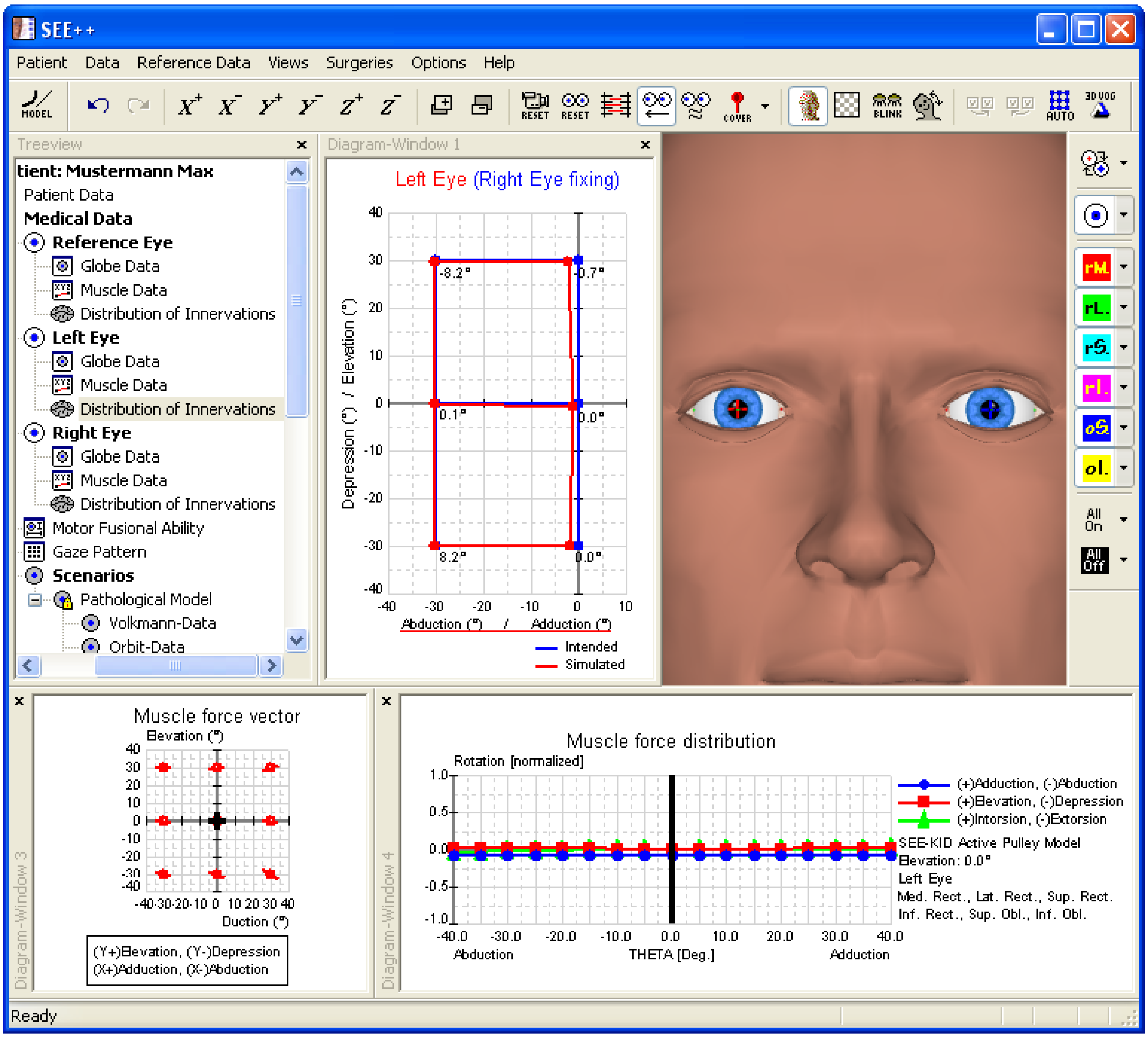
innervation of the lateral rectus muscle is changed from 100 % to **40 %** as shown in the following picture:



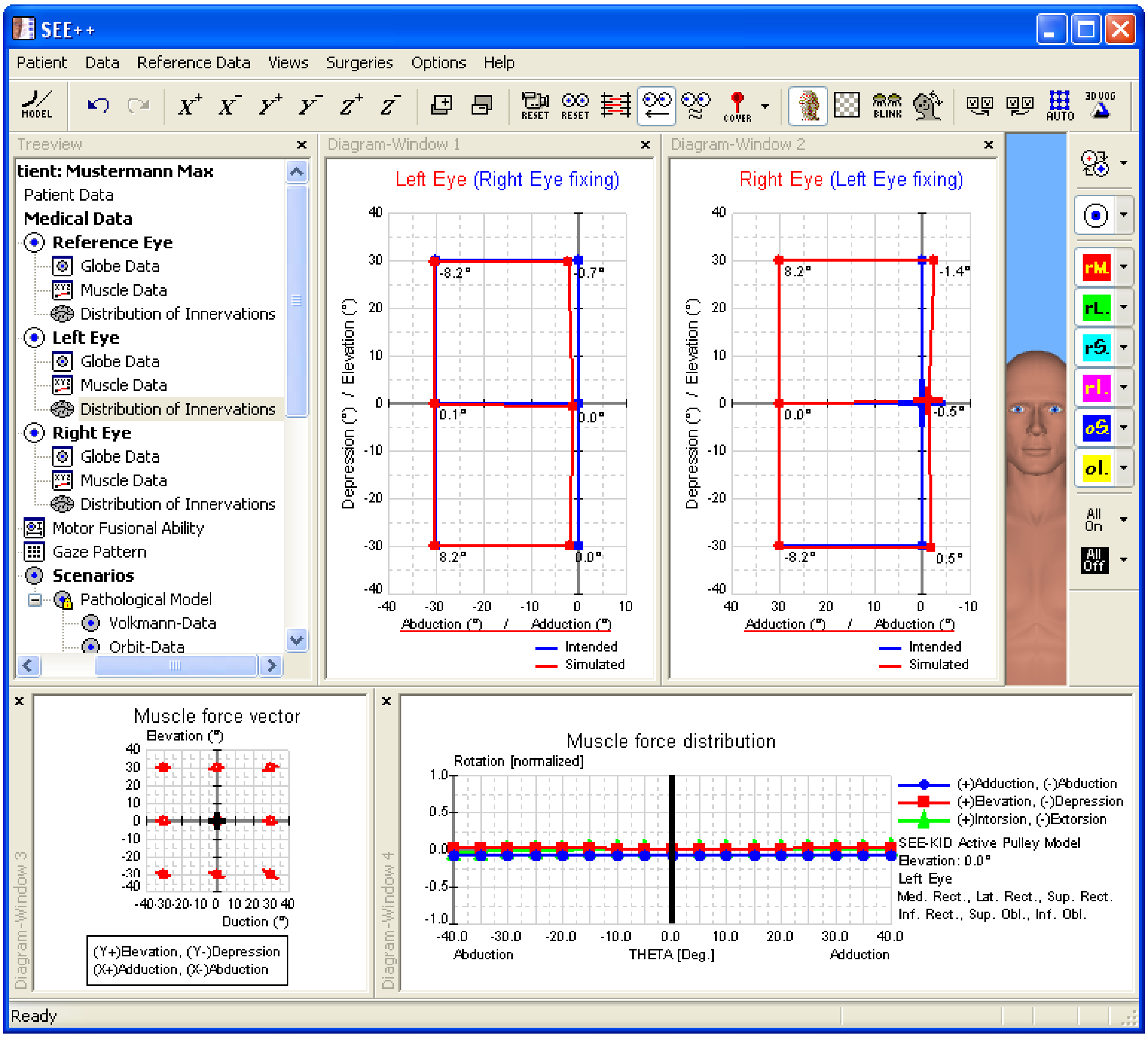
After closing the "Distribution of Innervations" dialog for the right eye by clicking on the "OK" button, the next step is to reduce the innervation of the medial rectus muscle of the left eye as well. Therefore, again, the "Distribution of Innervations" dialog is used (however, this time for the left eye) and in the dialog the innervation of the medial rectus muscle (Oculo/MR) is changed from 100 % to **40 %** according to the following picture:



When the Hess-diagram is recalculated now, the modifications from the "Distribution of Innervations" dialogs are immediately taken into account. By default, the Hess-diagram for the left eye (right eye fixing) is displayed in the diagram-window with the number 1. After the calculation of the Hess-diagram has been successfully finished, the following is displayed:



In order to display the second Hess-diagram for the right eye (left eye fixing), use the menu item *"Views" - "Diagram-Window 2"*. By default, the now displayed diagram-window with the number 2 displays the Hess-diagram for the right eye (left eye fixing). If this is not the case, you can simply click into one of the diagram-windows with the right mouse button and select the desired diagram in the displayed popup menu by left-clicking on it. If the size of the two diagram-windows is adjusted accordingly by clicking on the dividing line between the diagrams and resizing the diagrams with the left mouse button pressed, the following view is displayed:

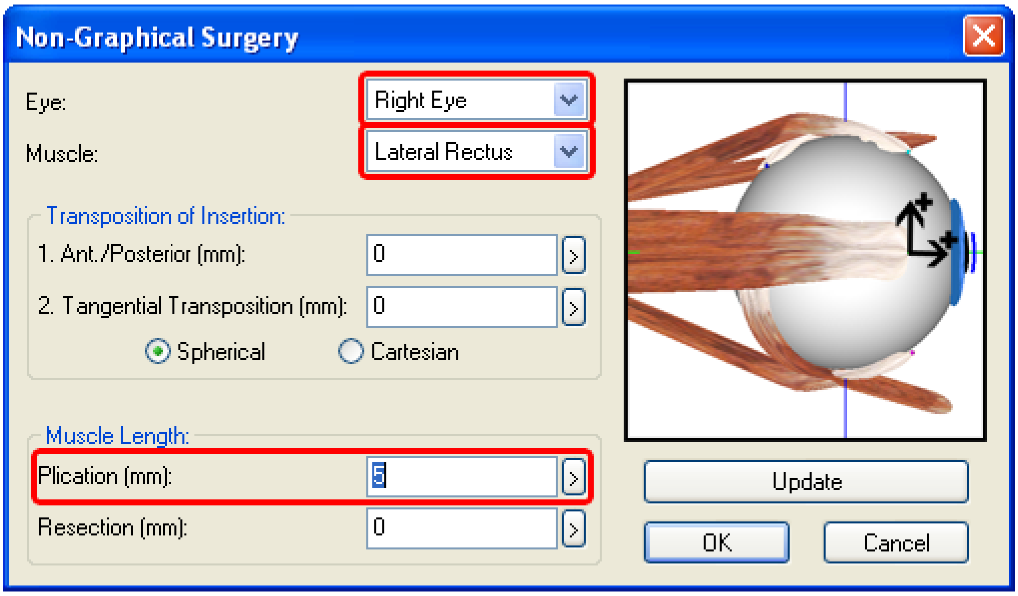


In the calculated Hess-diagrams for right eye fixing and left eye fixing the no longer existing right visual field can be clearly seen (missing conjugated eye movements to the right side). On the basis of the results of the simulation, which are shown in the Hess-diagrams, the simulation of the supranuclear gaze palsy can be considered as finished.

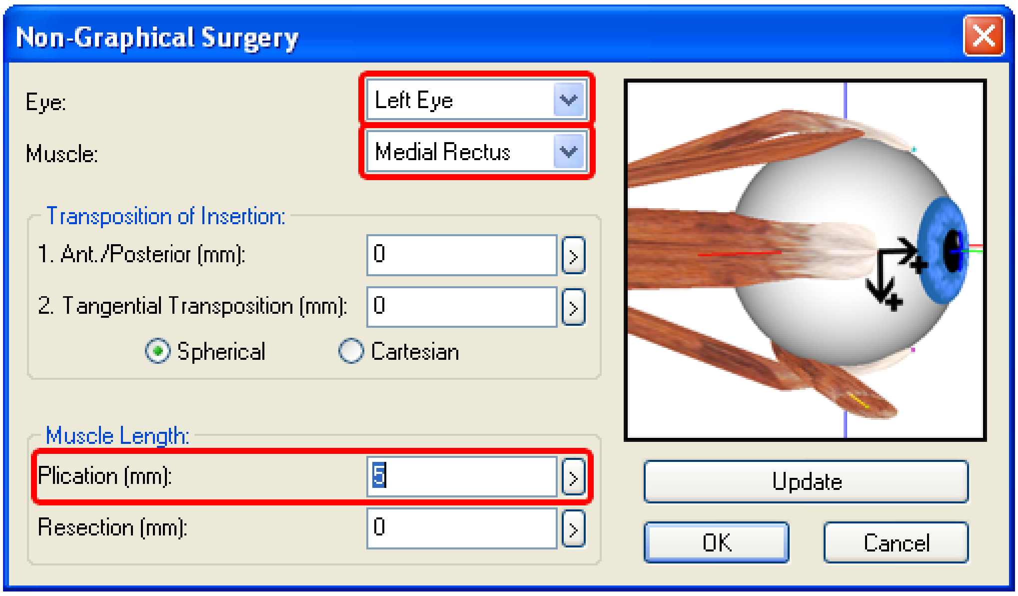
Surgical Correction

In order to be able to make better use of the visual field, which is shifted to the left for both eyes, and if a head posture (tilt to the right) is present, the attempt to simulate an (incomplete) Kestenbaum surgery will be made. The visual field of both eyes, which is shifted to the left due to the dexter gaze palsy, has to be shifted into the primary position. For that purpose, both eyes have to be "operated" to the right, i.e the lateral rectus muscle of the right eye has to be strengthened and vice versa the medial rectus muscle of the left eye has to be strengthened as well.

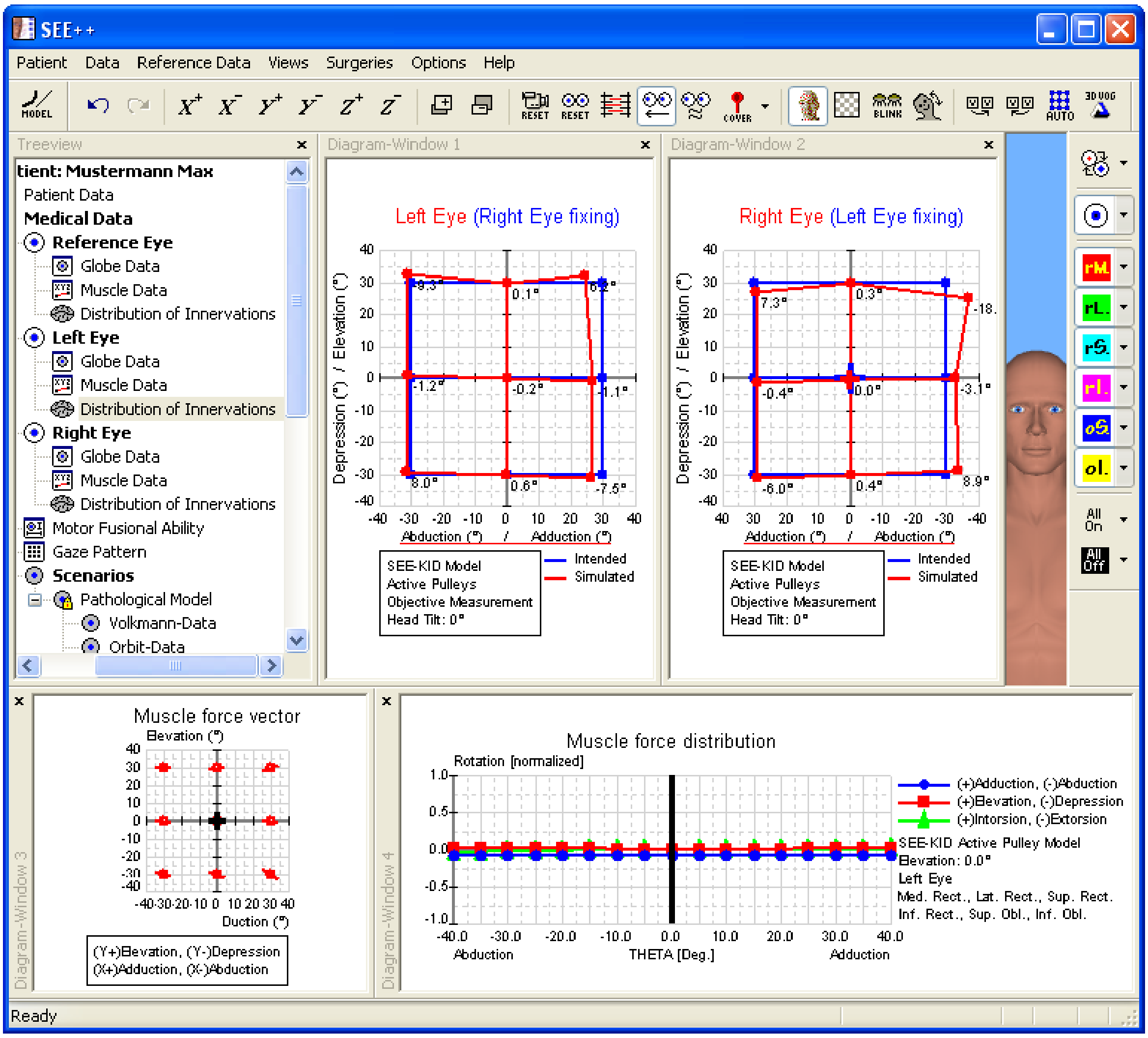
First a plication of the lateral rectus muscle of the right eye is carried out. In order to perform a plication surgery in SEE++, the "Non-Graphical Surgery" dialog is used, which is accessible by the menu item *"Surgeries" - "Non-Graphical Surgery"*. After the dialog has been opened, the desired eye and the desired muscle are selected, in this case the right eye and the lateral rectus muscle. Now a plication of 5 mm of the selected muscle is carried out by entering the appropriate value in the field "Plication (mm)". The following picture shows the dialog with the entered plication value:



With a click on "Update" the entered plication value is saved without closing the dialog. Now a plication of the medial rectus muscle of the left eye is carried out. Therefore, the left eye as well as the medial rectus muscle are selected in the dialog and a plication of 5 mm is entered in the field "Plication (mm)". The following picture again shows the dialog:



After closing the dialog with a click on the "OK" button, a plication of 5 mm on both muscles has been carried out and the program recalculates the two Hess-diagrams. When the calculation is finished, the following picture is displayed:



Now the two Hess-diagrams show that the goal of the surgical correction has been achieved in terms of the assumed pathology.

Part IV

4 SEE++ Reference

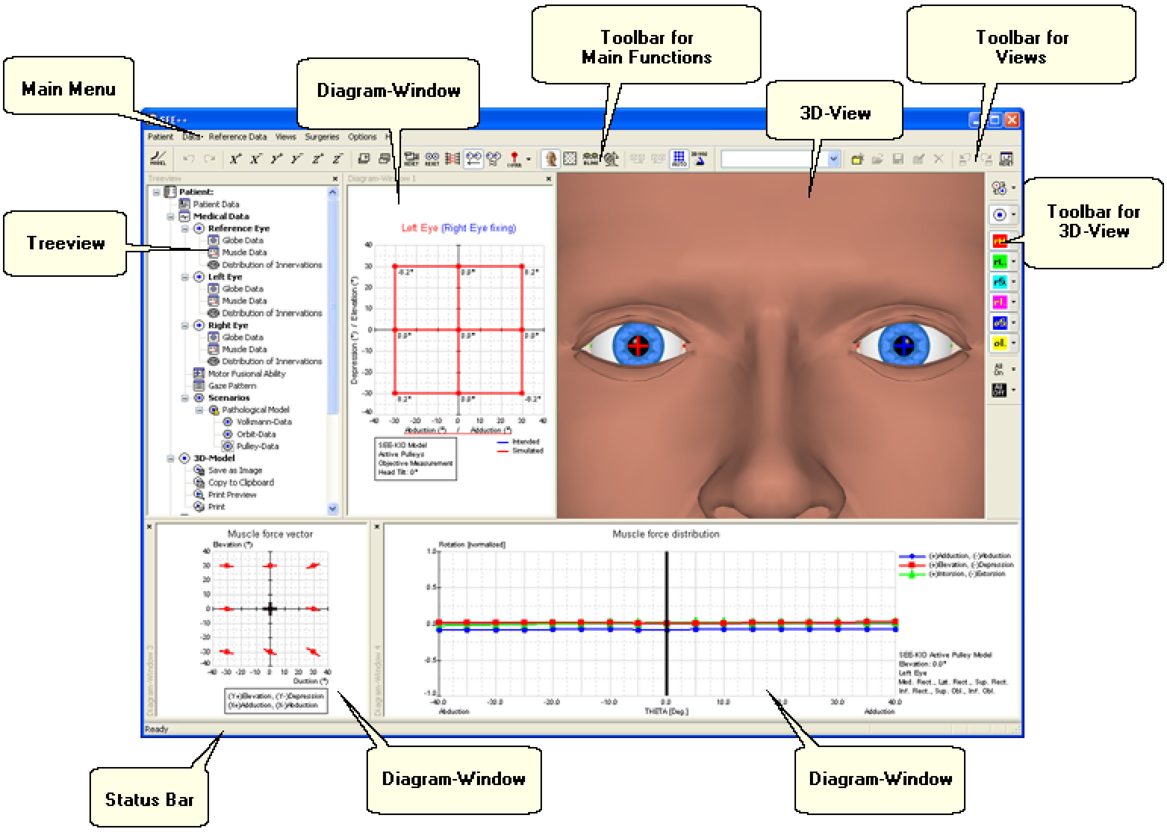
This part of the manual describes all functions provided by SEE++. You can access this help reference anytime from within the program via a "Help"-Button or by using the  key.

The basic symbols listed below are used throughout the whole text for explanation reasons:

	This symbol indicates an important **information** depending on the actual topic. You should pay attention to this information. This information often provides hints for a better system handling.
	This symbol announces an information that should be necessarily considered.
	Key shortcuts or special instructions handled by keyboard interaction are illustrated with the particular symbols of the adequate keys.

4.1 Overview

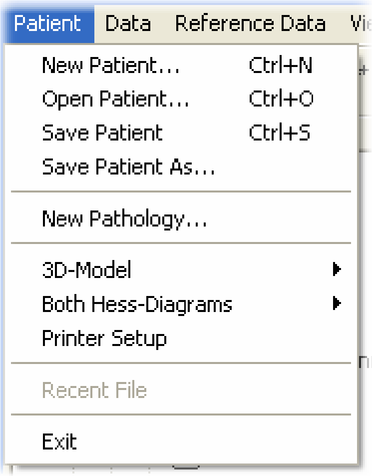
After starting SEE++ the following view of the main window is displayed:



When the program is launched for the first time this default view is shown. All program functions are available in a structured form via the **main menu**. Simultaneously the **Treeview** provides the same functions in a clearly arranged way through direct selection. The SEE++ system offers four different **diagram-windows** 109, which can display each diagram of choice. The individual diagram-windows 109 can be shown and hidden via the "Views" 109 menu. The **3D-view** 111 is an inherent part of the system, that displays the current simulation on a "virtual patient". To configure the 3D-view 111, which means showing or hiding muscles, globe, points of reference, etc., use the "3D-View Toolbar" 124. The "Main Functions Toolbar" 121 permits direct and fast access to the most important areas of the main menu as well as the Treeview and allows to switch the current model 120. The "Views Toolbar" 128 offers the possibility to manage different views. The status bar shows additional information depending on the current cursor position. If no additional information is available, the status bar displays solely "Ready".

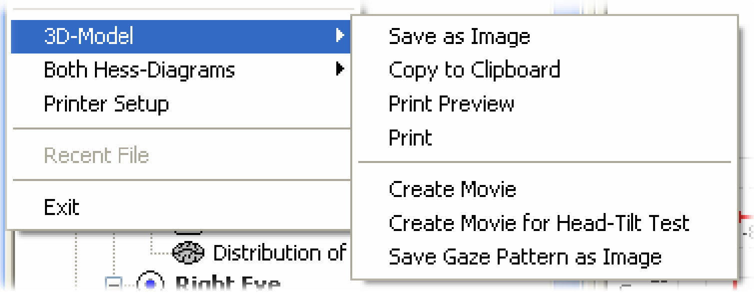
If due to the global settings of your operating system the language of the program is preset to German, you can use the "General Options" 141 dialog to change the language settings to English. Additionally, you can use this dialog to activate the OpenGL™ graphic acceleration, which enhances display quality and performance.

4.2 Patient Management

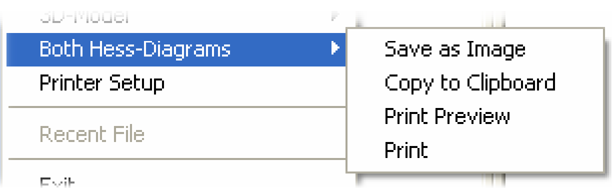


The patient management can be accessed via the "Patient" item of the main menu. In SEE++ a patient is saved as a dataset consisting of personal data 81 (name, birthdate, diagnosis, ...) and medical data 85 (globe data, muscle data, distribution of innervations, motor fusional ability and gaze pattern 91) structured in different scenarios 98. This dataset stores all necessary values for a complete simulation cycle 20 in a single file on the data storage medium. The stored files have the file extension ".eye" and can be opened with SEE++ via the Windows®-System by double-clicking on them. To create a new patient within the system, select the menu item "Patient->New Patient..." 81.

To save the current data in a new file, select "Patient->Save Patient As..." 82. If you want to save the data in the current file, select the menu item "Patient->Save Patient" 82. The menu item "Patient->Open Patient..." 82 loads a ".eye" or ".sye" file and adapts the whole program data to the last state stored in this file. If you create a new patient or load a patient file and you have not saved the current data, SEE++ displays a warning. By using the menu item "Patient->New Pathology..." 83 you can generate a new pathology for the current patient.



Furthermore, the menu item "Patient->3D-Model" provides a submenu with several functions to export the 3D-model. You can either save the current 3D-view as an image 149, copy it to the clipboard or print 157 it. The print preview 158 allows to check the image before printing. The special functions "Create Movie" 151 and "Create Movie for Head-Tilt Test" 155 offer the possibility to generate movie files. This allows you for example to save pathological situations as a movie for presentation reasons to get a better visualization of the desired situation. The option "Create Movie" is only available if a valid simulation is provided, which means, that at least one Hess-diagram (left or right eye fixing) has to be completely calculated and displayed. The function "Save Gaze Pattern as Image" 150 allows you to create a file that contains a view of the 3D-model from all 9 gaze positions of the default gaze pattern.



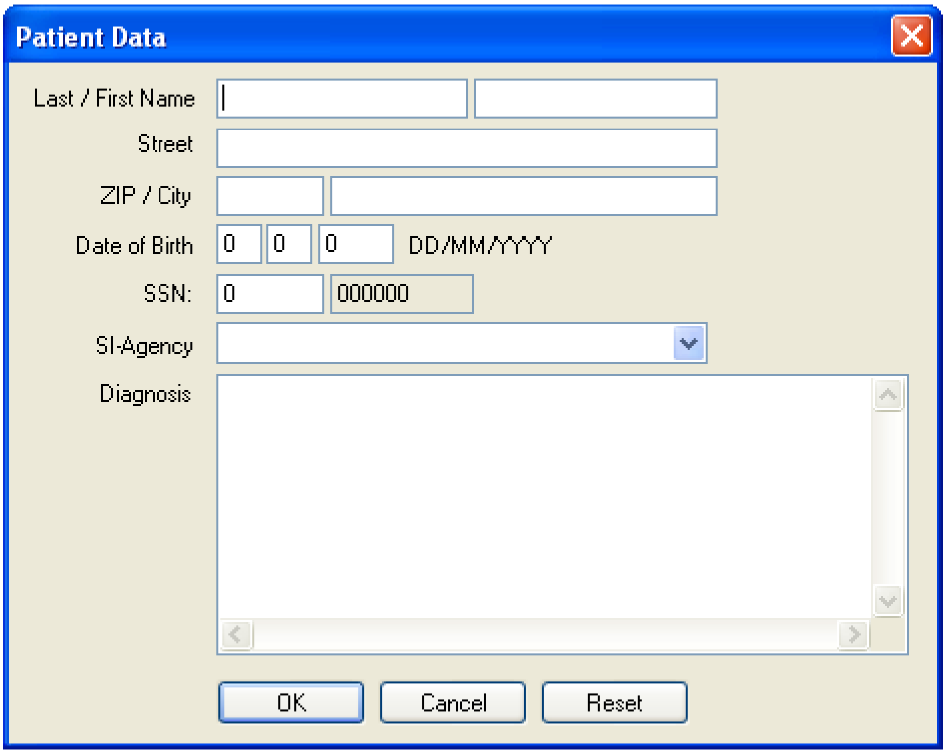
Additionally to the possibilities to export the 3D-model, the submenu "Patient->Both Hess-Diagrams" provides several functions to export both Hess-diagrams (left and right eye fixing) together. However, these functions are only available, if both Hess-diagrams are displayed in the program. You can save the Hess-diagrams as an image 149, copy them to the clipboard or print 157 them as well as check the image via the print preview 158 before printing it. To swap the default arrangement of both

Hess-diagrams (left eye (right eye fixing) on the left hand side and right eye (left eye fixing) on the right hand side), select the option "Swap Diagrams for Export" in the diagram options 146.

If more then one printer is installed on your system, you can configure the printer you want to use via printer setup 147. Below the menu item "Printer Setup" you can find a list including the last opened files (up to four files are shown) or the text "Recent File", if no file has been loaded yet. If you select one of these files, the program tries to load it. The file's entry is automatically removed from the menu in the case that the file does not exist on the data storage volume any more. The last menu item quits SEE++. If the current data was not saved in a file before, SEE++ displays a warning.

4.2.1 New Patient/Patient Data

Each time you create a new patient, the patient data dialog is displayed. Otherwise you can open the dialog via the main menu under "Data->Patient Data" or via the Treeview under "Patient Data". Fill out the blank fields or complete the missing information.

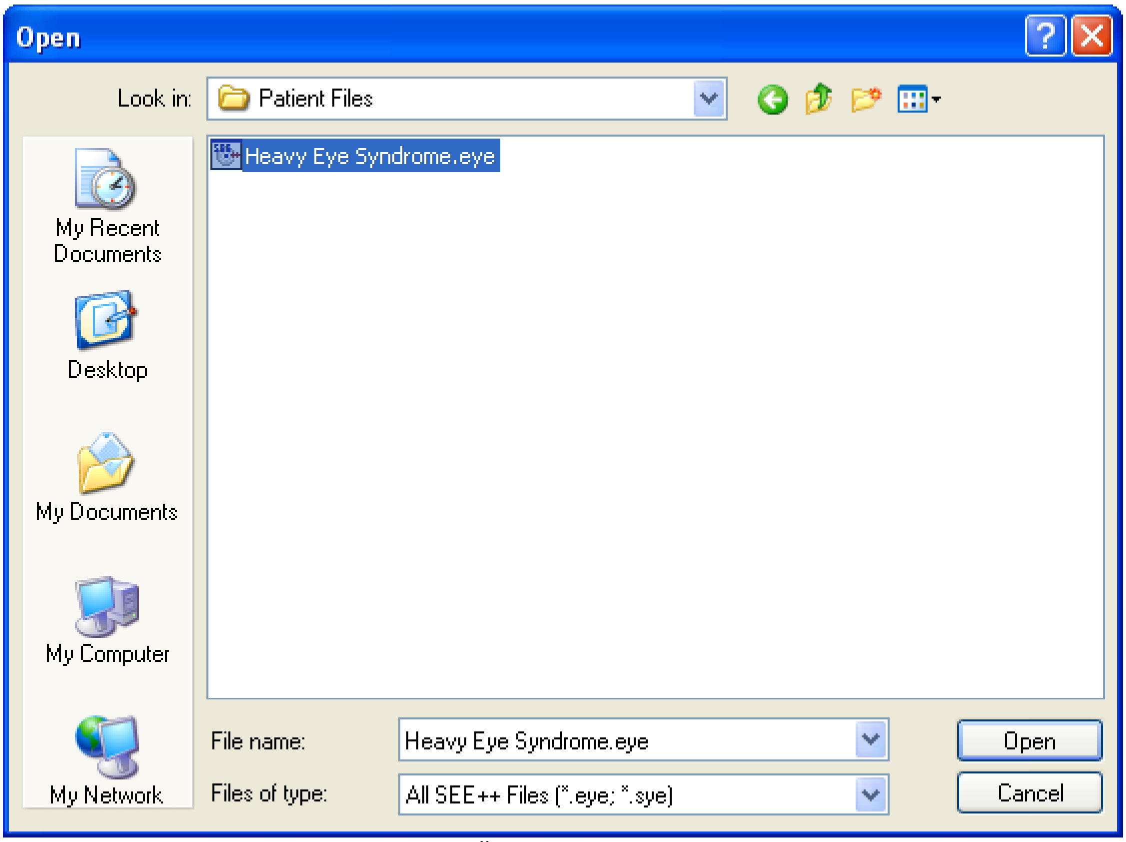


The diagnosis field allows the textual input of patient specific information to make it easier to find the simulation again later.
By hitting the "OK" button the input is confirmed and a new patient is created or already existing data is modified. If a new patient is created, all the model data is set to default values. The "Reset" button allows to cleanup all fields shown in this dialog. By hitting the "Cancel" button all data is discarded. No patient is created and changes are not saved.

Use the function "New Patient" only if you have already saved all current changes or if you want to discard the currently modified patient.

4.2.2 Open Patient

With the function "Open Patient" an already saved patient is loaded into the program. Navigate to the directory you saved your patient's data to and click on the desired patient file (.eye- or .sye-file).

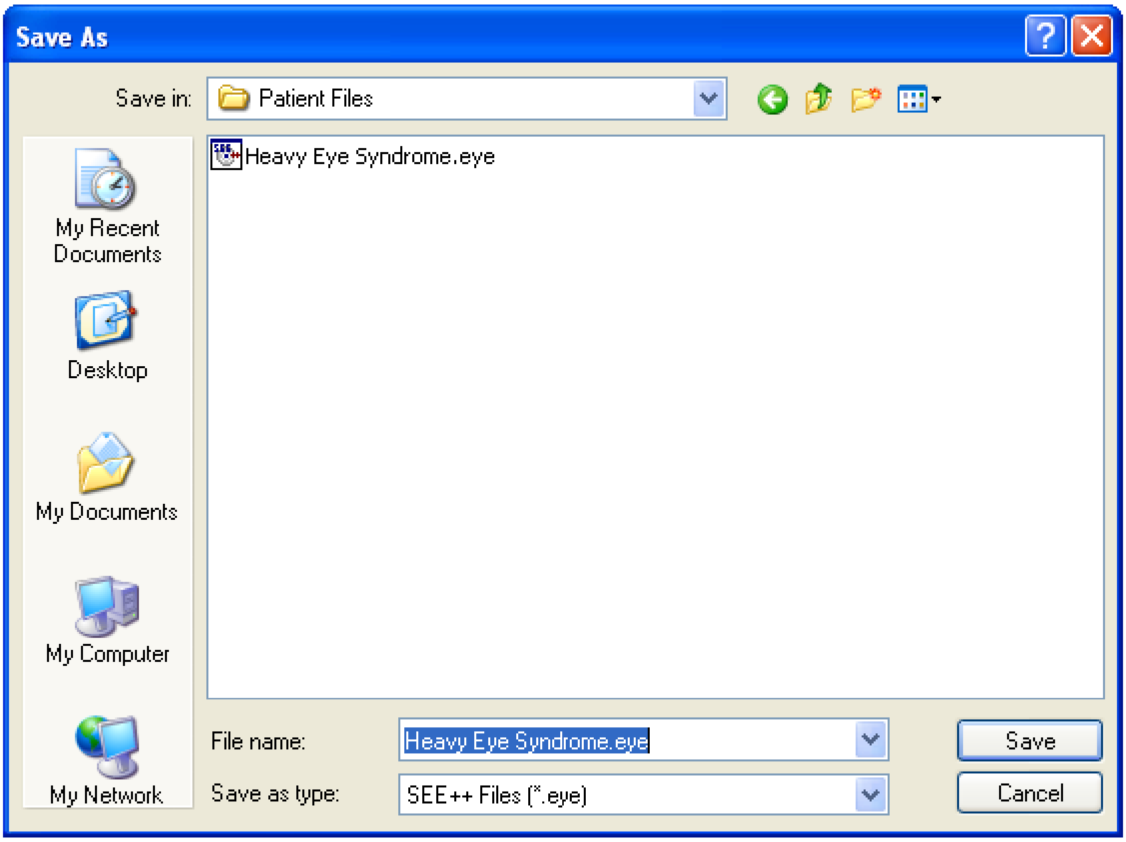


Confirm the dialog with the "Open" or "Öffnen" button to load the file into the program. If you hit the "Cancel" or "Abbrechen" button, no patient is loaded and the data used before you called the "Open Patient" function is retained unchanged.

When loading a patient, the patient who was active before is discarded. Ensure that you have saved the previously used active patient before you load a new patient file.

4.2.3 Save Patient

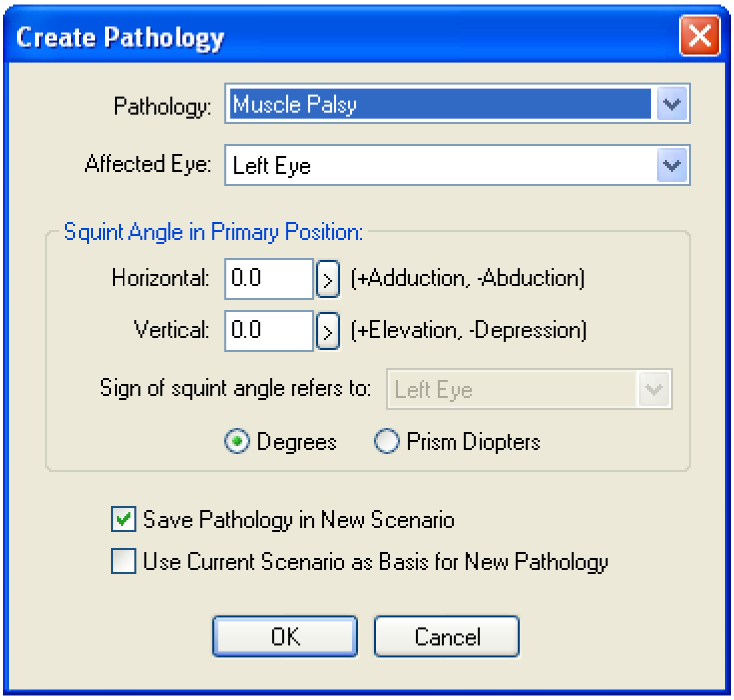
This menu item is used to save the current patient data as a file on your data storage volume. Navigate to the directory you want to save the patient data to and specify an adequate name for the file. Keep in mind not to specify a name already used in the chosen directory to avoid the overwriting of a file.



Confirm the dialog with the "Save" or "Speichern" button to save the current data as a patient file. If you hit the "Cancel" or "Abbrechen" button, the current patient is not saved and the data used before calling this function is retained unchanged.

4.2.4 New Pathology

With the help of this function you can generate a new pathology for the current patient. First choose the type of pathology you want to create as well as the affected eye. Then enter the measured horizontal and vertical squint angle in primary position. If you want to generate a pathology affecting both eyes, you have to additionally specify to which eye the algebraic sign of the squint angle refers to. The squint angle can either be entered in degrees or in prism diopters.



Via the option "Save Pathology in New Scenario" you can specify that newly created pathologies are automatically stored in a new scenario. The name of the scenario is automatically chosen based on the selected pathology. The second option "Use Current Scenario as Basis for New Pathology" provides the possibility to generate the pathology on basis of the current medical data contained in the currently chosen scenario. If this option is not selected, the pathology is generated on basis of the default data of an healthy human eye contained in the scenario "Pathological Model".

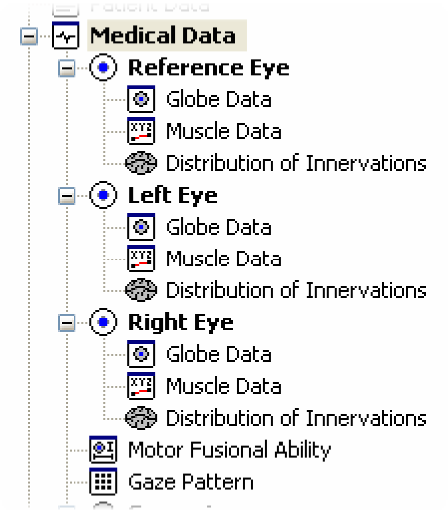
The generation of a pathology can take several time, depending on the computing power of the computer where the program is running. If it is not possible to generate the pathology with the chosen parameters, SEE++ displays an adequate error message. To get information about the parameters changed by SEE++ to generate the desired pathology, you can have a look at the activity log 104.

During the generation of a pathology, a dialog with the current calculation process and a "Cancel" button are displayed. By clicking on this button, you can abort the creation of the pathology anytime you like.

4.3 Medical Data

The medical data contains all necessary information for the modeling and simulation of a "virtual patient". Furthermore, some of the parameters of the medical data are used to specify pathological situations or to simulate surgeries.

The medical data contains information about the left, the right and the "Reference Eye" 51.



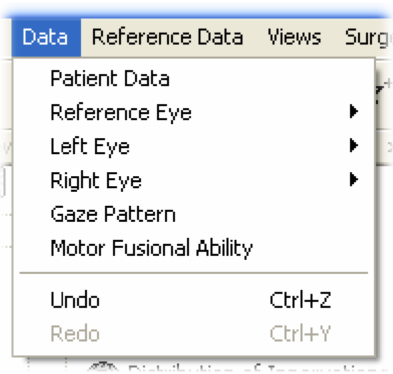
All eyes include the following:

- Globe Data 85
- Muscle Data 86
- Distribution of Innervations 89

For the progress of a simulation, a so-called gaze pattern 91 for the right eye fixing and/or the left eye fixing is additionally defined in order to specify the fixation positions for the Hess-Lancaster-Test 47. Furthermore, the motor fusional ability 90 can be defined, which is used for the simulation of the cover test 131.

Changes to the medical data can be stored as separate scenarios 98, which in turn can be saved in a patient file.

Do not forget to save all changes in a scenario that shall be traceable after loading a patient. Changes made to the medical data, which are not stored in a scenario, are automatically stored in a scenario called "Unsaved Data" when saving a patient.

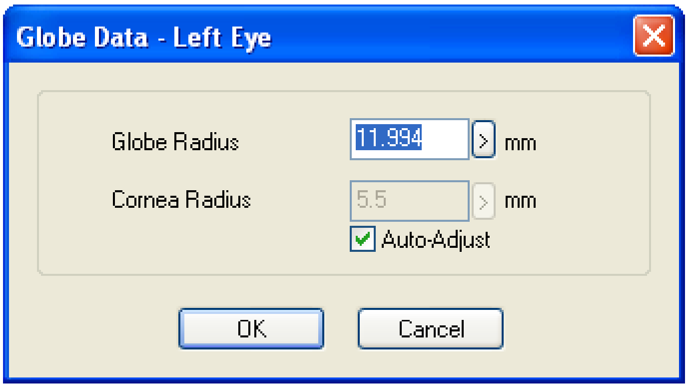


You can access the different medical data dialogs either via the Treeview or via the menu "Data". Furthermore, you can use the function "Undo" to undo up to 20 changes on the medical data (globe data, muscle data, distribution of innervations, motor fusional ability). If you want to restore an undone change you can achieve this via the "Redo" function. After clicking on "Undo" or "Redo", a dialog shows up displaying the corresponding changes. If you confirm this dialog by hitting "OK", the change is executed.

You can disable this dialog in the general options 141. If you do so, changes are directly executed, without displaying a confirmation dialog.

4.3.1 Globe Data

The globe data dialog exists for each eye simulated by SEE++ 41. In this explanation the left eye is used as an example. All specifications can be applied analogously for the right eye and the reference eye.
You can access the globe data dialog via the main menu under "Data->Left Eye->Globe Data" or via the Treeview under "Medical Data->Left Eye->Globe Data".

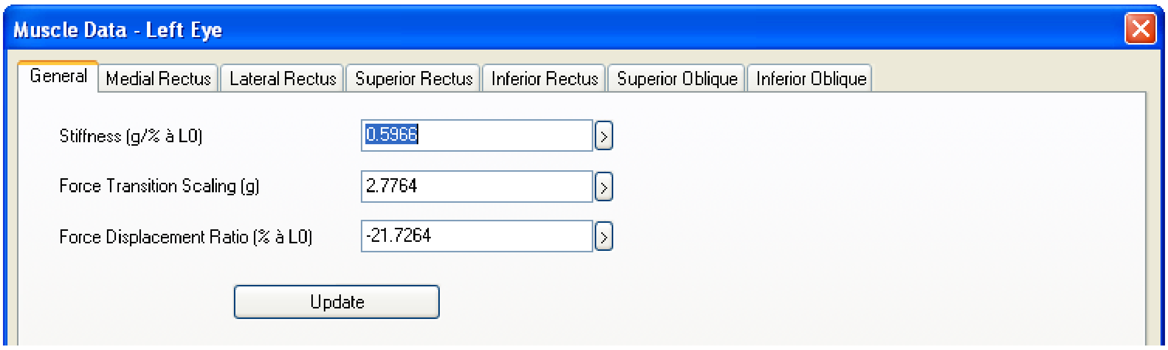


This dialog allows you to change the "Globe Radius" and the "Cornea Radius". The default values depend on the selected geometric model 34. The globe radius has significant influence on the simulation results, because a larger or smaller radius results in a different muscle force direction on the globe. If this value is changed, additionally all insertion points and pulleys 37 (functional origins) of all muscles of the corresponding eye are adapted. Modifications of the cornea radius only affect the visualization as well as the area where the muscle insertions are allowed. The simulation result is not affected. If the option "Auto-Adjust" is activated, the cornea radius is automatically adjusted to the size of the entered globe radius.

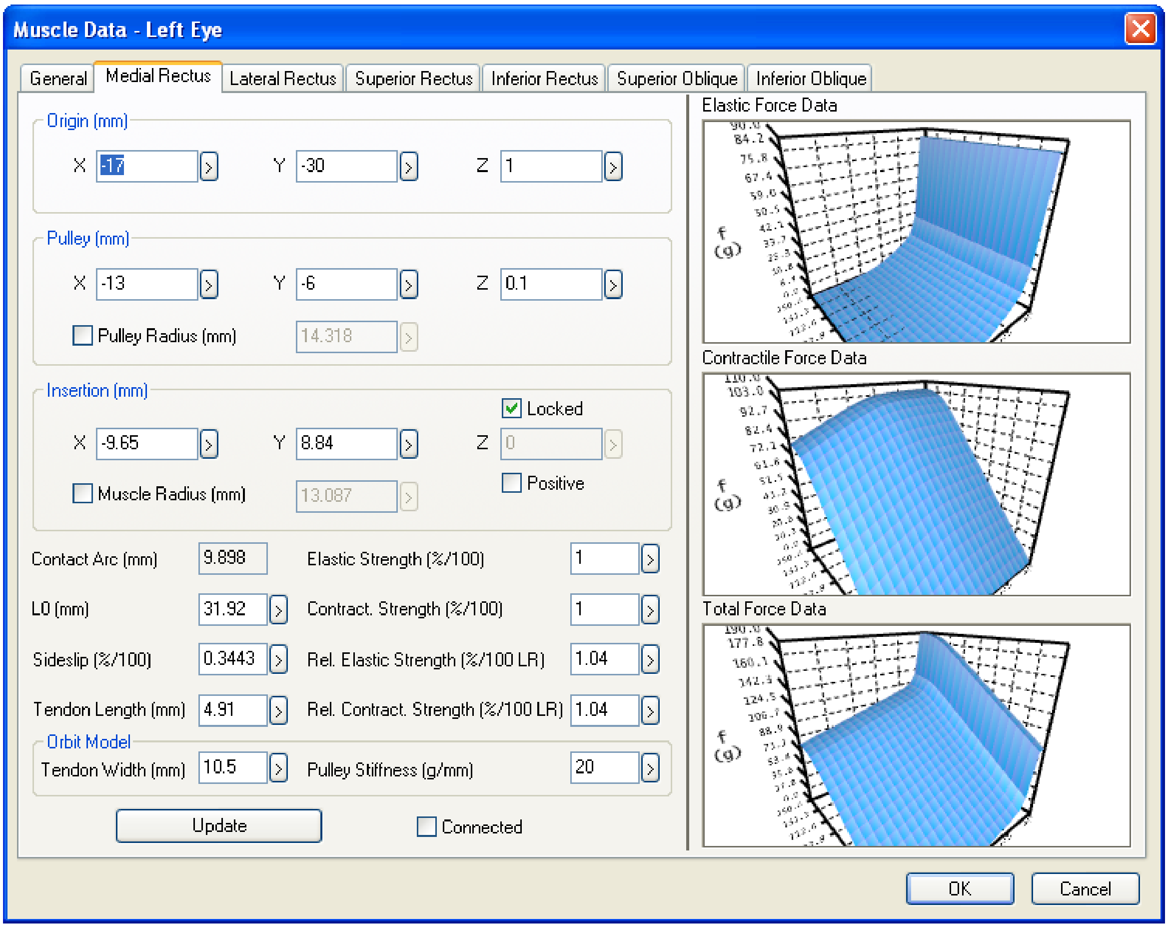
Due to the restriction, that muscle insertions in the "virtual surgery" are not allowed to be transposed into the pupil, a change of the globe or cornea radius possibly cannot be accomplished as desired.

4.3.2 Muscle Data

The muscle data dialog is one of the most central elements in the SEE++ system. It can be used to adjust the force model to pathological conditions regarding to single eye muscles. All data contained in this dialog changes the force development of all or some particular muscles. Therefore, muscle paresis, hyperfunctions and fibrosis can be simulated.
The muscle data exists for each eye simulated by SEE++ 41 (left eye, right eye and reference eye). In this explanation the left eye is used exemplary again.
You can access this dialog via the main menu under "Data->Left Eye->Muscles" or via the Treeview under "Medical Data->Left Eye->Muscle Data". The dialog consists of various "tab sheets", whereas each tab sheet represents one of the six eye muscles. Additionally, the tab sheet "General" summarizes the settings that are applied on the whole model. Simply choose your desired tab sheet by clicking on the corresponding heading with the left mouse button. Another possibility to directly access the tab sheet of a muscle is to perform a short double-click with the left mouse button on an insertion point in the 3D-view 111.
By default this dialog is displayed with the active tab sheet "General". It can be used to change the three general parameters of the force model 41. Confirm your changes by hitting the "OK" button or discard them by clicking on "Cancel". The button "Update" allows an immediate update of all changes without the need to close the dialog. That means that SEE++ instantly performs the calculation of the Hess-Lancaster-Test with the changed values. This option is useful if, additionally to the general settings, changes to muscle-specific parameters 44 will be made before closing the dialog.



If you now choose one of the tab sheets, you will recognize that the different sheets are (nearly) identical for all muscles:



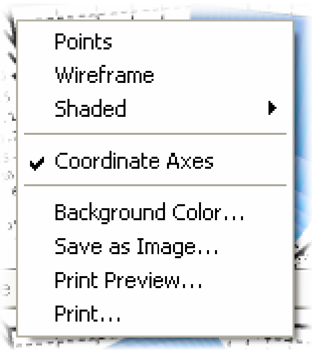
First of all this dialog provides the possibility to manually change some geometric properties (origin, pulley and insertion) of a muscle. All coordinates have to be specified according to the chosen eye in the defined head fixed coordinate system 17. These parameters cause a change of the muscle path and therefore influence the simulation result. All values are defined in primary position. That means that even when the 3D-view 111 displays another eye position, the geometric values of the muscle dialogs always refer to the primary position 16. If you want to know the geometric values of a certain gaze direction, you can use the Stateviewer 118 to get that information.

The visualization of the three muscle curves 39 on the right hand side of the dialog is based on the 3D-view 111. Each diagram is an independent view and can be arbitrarily rotated, scaled, printed and saved as an image. The checkbox "Connected" is used to equate the view of the single curves among each other. That means that if you change the view of one 3D-curve with your mouse and the "Connected" checkbox is checked, all other curves follow automatically.
The "Update" button allows an immediate update of all changes without the need to close the dialog with "OK" in the same manner as already described for the "General" tab sheet. SEE++ immediately starts with the recalculation of the simulation results in the background after clicking on "Update".

The following possibilities exist to modify the visualization of the 3D-muscle-curves:
While navigating with the mouse, first always click into the muscle curve with one mouse button, keep the button pressed and then move the mouse while still pressing the mouse button. Simply release the mouse button to stop.

Mouse Button/Button	**Action**
Left mouse button	Rotate the whole muscle curve (camera rotation) with the help of a "virtual hemisphere". Within this sphere the rotation is done around the x- and z-axes and outside around the y-axis.
Rotate the mouse wheel *or*  + left mouse button	Zoom in or zoom out the whole view (zoom function).
Click the mouse wheel *or* middle mouse button	Reset the 3D-view to the initial position (camera reset).
	Reset the view of all three 3D-muscle-curves to the initial position (camera reset).
Right mouse button	Open the menu for the display options.

In a 3D-curve the menu for the display options is opened by clicking the right mouse button.



The curve view can be displayed in three different ways:

- Points - the muscle curve is displayed as points
- Wireframe - displays a wireframe model of the curve
- Shaded - choose between a stripes or quadrangle view

The option "Coordinate Axes" shows or hides the whole diagram marking. The function "Background Color..." allows to change the background color of the diagram.
If you choose "Save as Image...", the dialog to save an image 149 is displayed. The functions "Print..." 157 and "Print Preview..." 158 open the appropriate Windows® default dialogs.

Change the Pulley Position

Basically, the pulley of a muscle can be moved arbitrarily in the 3D space. This task is hard to achieve manually. Therefore, the checkbox "Pulley Radius" allows you to enlarge or decrease the distance to the rotation center of the globe (coordinate system zero point). If you click on the checkbox with the left mouse button so that it is ticked and adapt the pulley radius, the coordinates of the pulley in x-, y- and z-direction are automatically calculated via the distance formula of the vector to the zero point of the coordinate system 17.

Change the Insertion

The insertion point of a muscle usually is directly coupled to the globe. Therefore, a "free" positioning in the 3D space is hard to estimate. The checkbox "Locked" allows to automatically define the z-coordinate via insertion into the spherical equation of the globe, so that only the x- and y-coordinate are arbitrary. Choosing the x- and y-coordinates in an adequate way still permits two possibilities to position the insertion point on the globe (front or back hemisphere). This is achieved by ticking off the checkbox "Positive". If the checkbox "Positive" is ticked, the z-coordinate of the calculated insertion point is used, that points along the positive z-axis direction of the used coordinate system 17.
Another possibility to define an insertion point of a muscle is to use the checkbox "Muscle Rad.". The same principle such as the one used by the determination of the pulley position via the "Pulley Radius" is applied here. The insertion point is displaced according to the "Muscle Radius" along the vector pointing to the origin of the used coordinate system.

The geometric abstraction of the globe is reduced to a sphere. However, a real globe is unlikely to be based on a perfect sphere. Therefore, it is possible, that in the 3D-view some muscles do not directly touch the globe in the area of the insertion. Since the insertion points used in SEE++ were measured as complete 3D points and were defined according to an ellipsoid shaped globe, a separate "virtual" globe radius is assigned to each muscle.

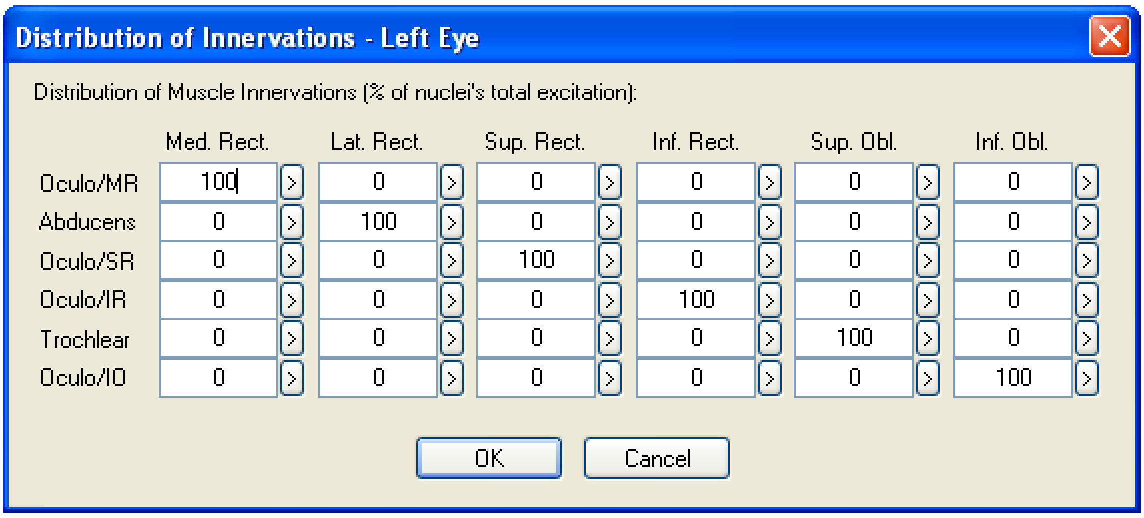
Change the Muscle-Specific Parameters

The muscle-specific parameters form the core of the configurable muscle model. The specific force data (contractile, elastic and total force) can be directly influenced here. The value "Contact Arc" is not changeable and therefore forms an exception. This value displays the contact arc 16 of a muscle in primary position, resulting of the geometrical properties as a spherical distance between the insertion point and the point of tangency 16. The values have to be adopted according to the explanations denoted in the chapter describing the "force model" 44.

4.3.3 Distribution of Innervations

The distribution of innervations dialog controls the muscles activation potential based on the stimulations created by the motor nuclei of the cranial nerves. This distribution is directly mapped to the innervations of each eye and therefore does not represent the real anatomical structure unambiguously. Rather different nuclear interferences can be modeled through adequate adaptations of the distribution of innervations for the left and/or the right eye.

The distribution of innervations exists for all eyes that can be simulated with SEE++ 46 (left eye, right eye and reference eye). This explanation uses the left eye exemplarily. You can access this dialog via the main menu under "Data->Left Eye->Distribution of Innervations" or via the Treeview under "Medical Data->Left Eye->Distribution of Innervations".

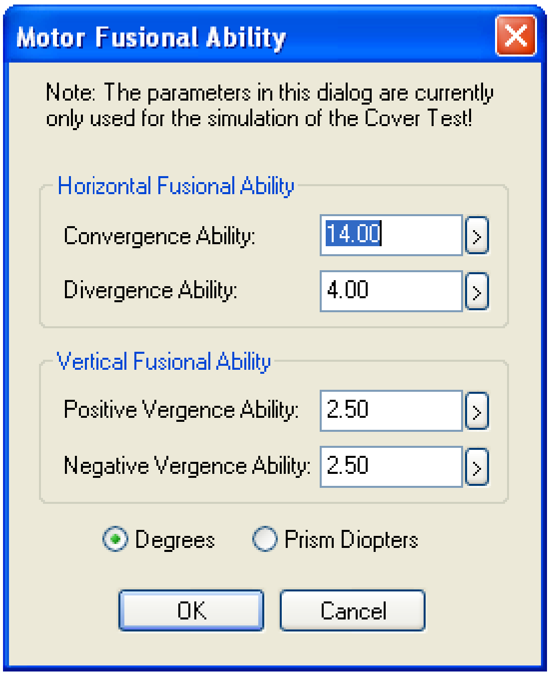


For a detailed explanation of the effects caused by changes see the chapter force model 46 (motor nuclei).

All values provided in this dialog are specified in percentage.

4.3.4 Motor Fusional Ability

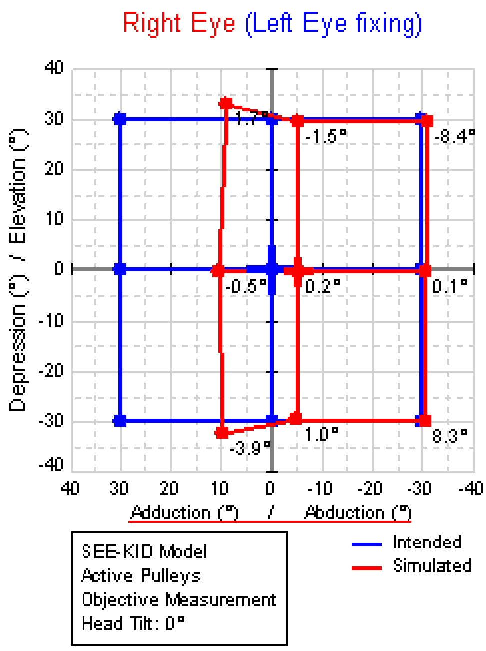
This dialog provides the possibility to change the motor fusional ability of the "virtual patient". The motor fusional ability can either be entered in degrees or in prism diopters. If you close this dialog using the "OK" button, the new values are stored. If you click the "Cancel" button, all changes are discarded. You can access this dialog via the main menu under "Data->Motor Fusional Ability" or via the Treeview under "Medical Data->Motor Fusional Ability".



Changing the motor fusional ability does not cause a recalculation of the Hess-Lancester-Test, because currently the fusional ability values are only used for the simulation of the cover test 131. Therefore, these parameters have no influence on the calculation of the Hess-Lancester-Test.

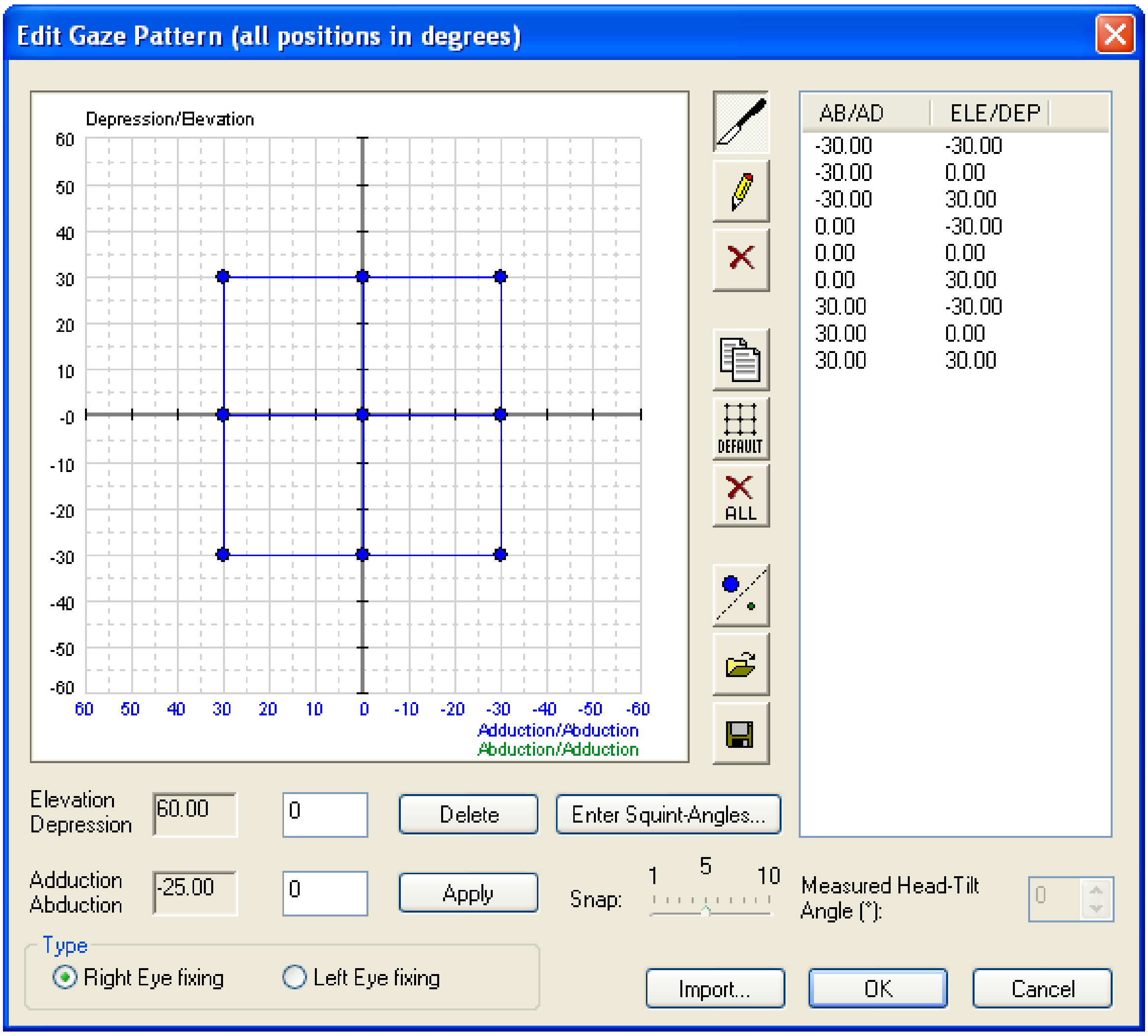
4.3.5 Gaze Pattern

A gaze pattern forms the basis for the simulation of the Hess-Lancester-Test. When executing the simulation for each point drawn into the gaze pattern, a fixation of the particular fixing eye is accomplished. According to the description of the simulation, the other eye is considered as the following eye and diverges, depending on the pathological situation, from the fixing eye. Within the Hess-Lancester-Diagram the blue points represent the fixation positions denoted by the gaze pattern and the red points describe the resulting deviation points of the following eye.



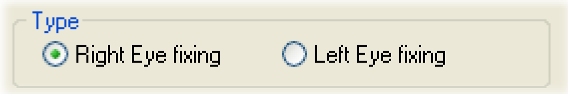
A left eye fixing is denoted here as an example. This means that the left eye consecutively fixates gaze positions shown in blue and then the SEE++ system calculates the position of the in this case right following eye with a given pathology (in this case a paresis of the right medial rectus muscle). The squint angle can be determined through the comparison of the neighboring blue and red points. The given blue gaze pattern can be modified in the gaze pattern dialog. There exists a complete gaze pattern for the right eye fixing and the left eye fixing, because the Hess-Test is executed for both eyes (first left eye fixing, then right eye fixing or the other way round). The modification of a gaze pattern is necessary when the fixing eye reacts pathological and therefore cannot reach certain fixation points (blue) any more. Then you can either delete these points or change the gaze pattern in such a way that a fixation is possible again.

You can access the dialog to change a gaze pattern via the main menu under "Data->Gaze Pattern" or via the Treeview under "Medical Data->Gaze Pattern".

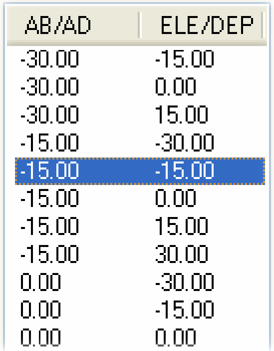


This dialog allows the modification of the gaze pattern of the current scenario. If you want to edit the gaze pattern of another scenario, you first have to set the desired scenario active (see scenarios 98).

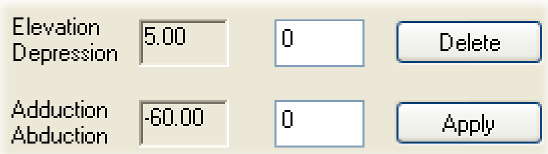
The gaze pattern dialog shows the current gaze pattern, displayed in blue, for one fixation direction. You can switch between the gaze pattern for left eye fixing and right eye fixing via the "Type" box.



The point list shows all entered fixation points in textual form:



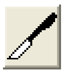
You can select a point with a single click on a particular entry. Then the coordinates of the chosen fixation point are shown in the text fields for changing and deletion. Furthermore, the point is marked red in the gaze pattern.



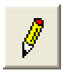
Single fixation points can be edited by textually entering the data into the free fields for elevation/depression and adduction/abduction.

Confirm an entered point with "Apply" or delete the actually marked point in the list with "Delete".

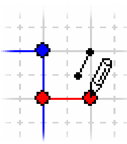
If you want to use the mouse to edit the points, you have to use the provided buttons:



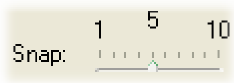
Push this button, if you want to move the points within the gaze pattern with the mouse. To move a point, navigate the mouse over the desired point, press down the left mouse button and then, while still pressing the mouse button, pull the point to the desired position.



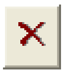
Push this button to insert new points into the gaze pattern. Then move the mouse to the desired position in the diagram and insert a new point by clicking the left mouse button once.



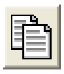
Moreover, this function offers the possibility to connect two points with each other. You can achieve this by left-clicking on an existing point and then, while still pressing the mouse button, pulling a line to another point. The line is drawn, when you release the left mouse button over the target point.



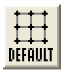
The snap defines the step size that the points can be moved or set within the gaze pattern with the mouse. A snap of 5 is equivalent to a step size of 5°. Reduce the snap to place points more precisely with the mouse.



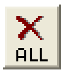
Push this button to delete single points within the gaze pattern. Move the mouse over the point to delete in the diagram and delete it by clicking the left mouse button once.



This button allows you to copy (blue or green) points of one fixation into another fixation. SEE++ displays a warning, if existing points are going to be overwritten.

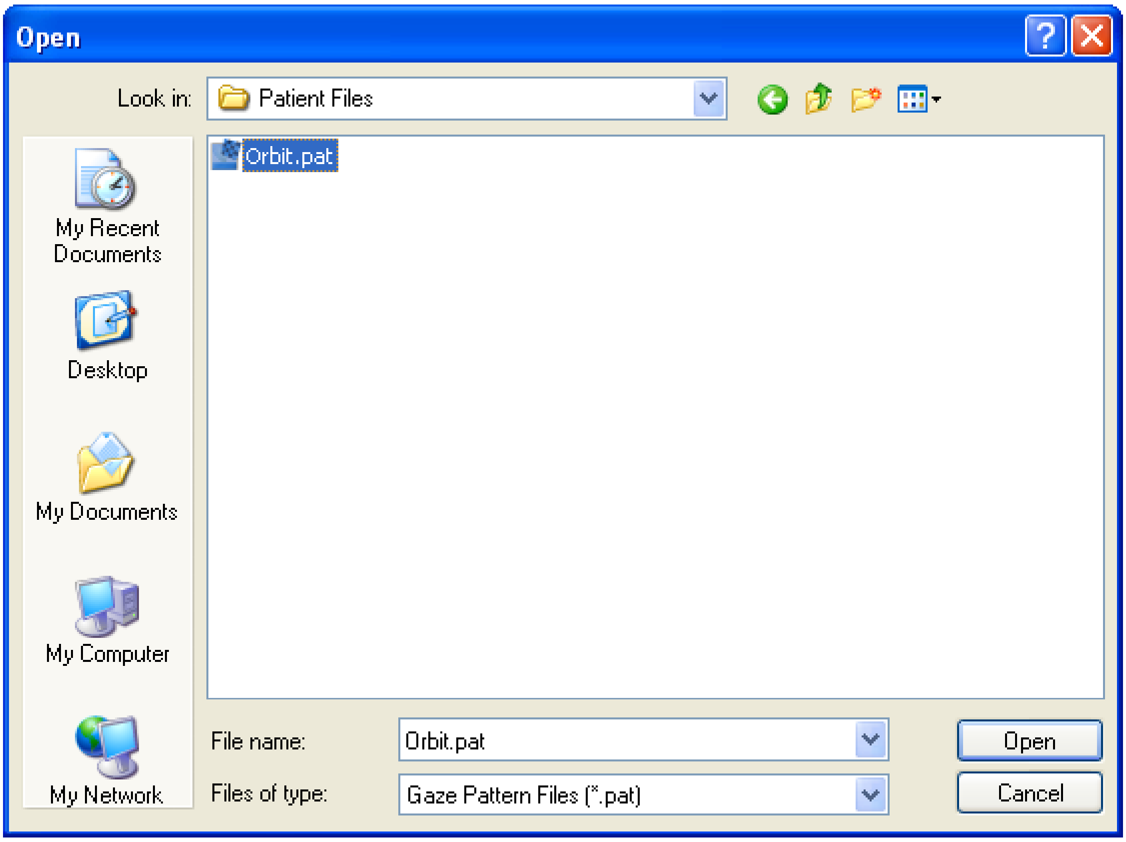


Pushing this button deletes all points of the current gaze pattern and replaces them with the default gaze pattern (9 points in the main gaze directions with an maximum gaze angle of 30° each).



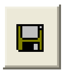
This button deletes all fixation points within the current gaze pattern.

With this function you can load a gaze pattern from a file. When loading a gaze pattern file, the current gaze pattern is replaced by the one from the file.

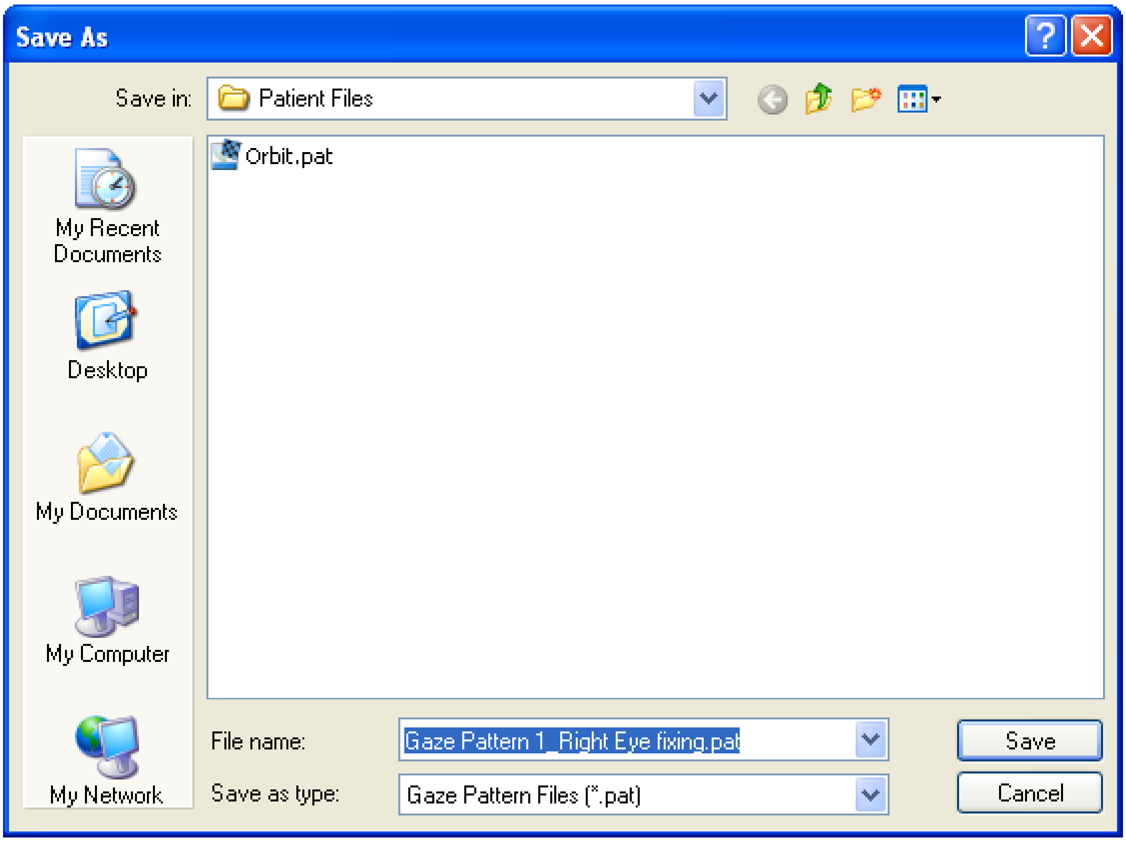


After clicking the button to load a gaze pattern, the dialog to choose a gaze pattern file is displayed. These files have the extension ".pat". Navigate to the desired directory and select the .pat-file you want to load. Then hit the "Open" or "Öffnen" button to load the file. If you push the "Cancel" or "Abbrechen" button, no file is loaded and the current gaze pattern is retained unchanged.

Remind that loading and saving gaze pattern files only affects the gaze pattern of the currently selected fixation and the currently selected points. That means that either only the blue or the green points for the left eye fixing or the right eye fixing are stored or replaced. If you want to replace the gaze pattern for both fixations, you have to switch the fixation to e.g. left eye fixing and again load a gaze pattern file. Another possibility is to copy a gaze pattern into the other fixation by clicking the button to copy a gaze pattern.

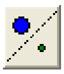


Use this function to save an existing gaze pattern to a file. Files which save gaze patterns have the extension ".pat" and can be loaded anytime in the gaze pattern dialog via the open function (see above).



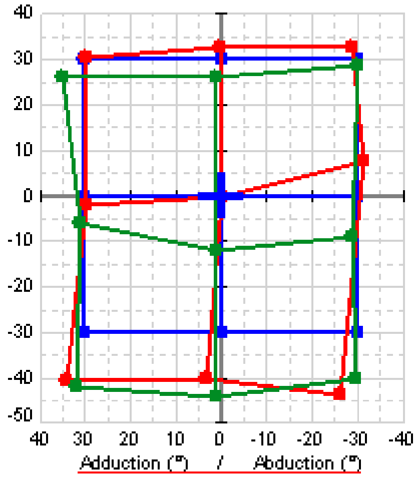
After clicking the button to save the gaze pattern, the dialog to choose a location and a filename is displayed. Go ahead like you have done when opening a gaze pattern. Navigate to the desired directory and after naming the file, store it by clicking the "Save" or "Speichern" button.

Besides the fixation gaze pattern for the Hess-Lancester-Test simulation, SEE++ offers an additional alternative to draw a "real" gaze pattern clinically measured on a patient for comparing reasons.



This button switches between blue and green points. The green points represent real patient data. The drawing of the green gaze pattern for right eye fixing as well as for left eye fixing works in the same way as was explained for the fixation points for the blue gaze pattern (see above). Loading and saving of green gaze patterns can as well be applied analogously.

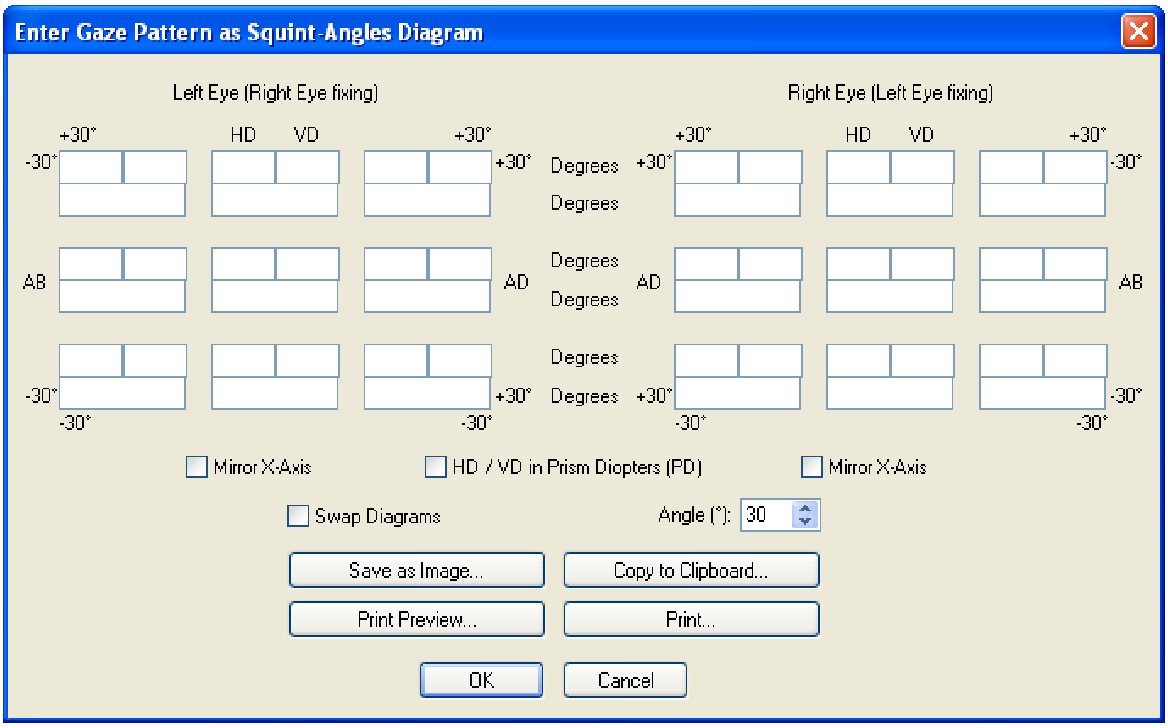
When using a measured green gaze pattern, there exists the additional possibility to specify in which head-tilt the gaze pattern was measured. The entered head-tilt angle is displayed in the additional information box of the Hess-diagram. However, it has no influence on the simulation.



If the Hess-Lancester-Test was simulated with SEE++ and the results are displayed, the green "measured" gaze pattern, if it was defined in the gaze pattern dialog, is additionally displayed. This allows an easy direct comparison between the simulation and the clinically measured data.

In the computer system Orbit™ the gaze patterns are saved to the single "simulation file" as well. SEE++ offers the possibility to import a gaze pattern from an Orbit-File. To achieve this, use the "Import..." button. The procedure is handled in the same way as when loading a SEE++ gaze pattern file (.pat file).

The "Enter Squint-Angles..." button enables you to enter a gaze pattern via a template for the nine main gaze directions.

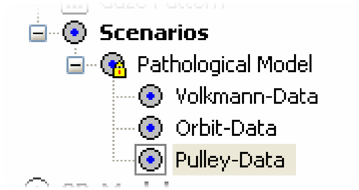


Besides the input of the horizontal deviation (HD), the vertical deviation (VD) and the torsional angle (see simulation 51) the textual input offers the possibility to swap the diagrams in all horizontal axes. That is because the clinical usage is not always standardized.
Use "Mirror X-Axis" to mirror the entered points in the particular diagram. Use "Swap Diagrams" to swap the left eye fixing and the right eye fixing. By default the convention of the sight of the patient is used, which means that in the examiners view the **patient's right eye** is **left**. The maximum gaze angle for the nine main gaze directions can be adjusted with the "Angle" field. Furthermore, the deviations can be entered in degrees and prism diopters. If you want to skip one point (because for example it couldn't be fixed by the patient), you can simply delete the complete content (0.0 has to be deleted too!) of the three deviation fields (HD, VD and torsion) of the appropriate point or leave all three fields empty. In case no torsion has been measured in a specific gaze direction, simply delete the content of the corresponding torsion field or leave it empty (0.0 would mean a measured torsion of 0 degrees).
A textually entered gaze pattern can be saved as an image 149, copied to the clipboard or printed 157. Furthermore you can check the gaze pattern you want to print via the print preview 158.

Remind the different algebraic sign for the right eye fixing and the left eye fixing 51, which **only** applies when using the textual input.

4.4 Scenarios

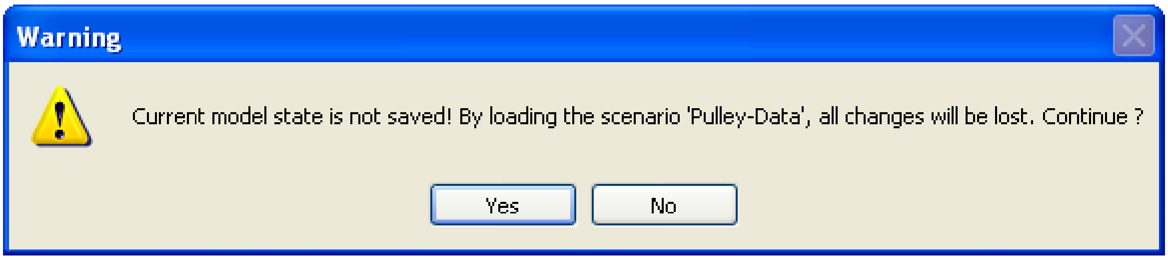
Scenarios can be edited exclusively via the Treeview. In a scenario all three eyes (reference eye, left eye, right eye) with all the corresponding medical data 85 (globe data 85, muscle data 86, distribution of innervations 89, motor fusional ability 90, gaze pattern 91) are stored. Furthermore, each scenario can have an ambiguous name that needs to have a minimum length of five characters. All scenarios can be found under the "Scenarios" element in the Treeview. By default there exist four scenarios in SEE++:



- **Pathological Model:** This scenario contains the original data for all other scenarios (default data). It cannot be deleted, overwritten, renamed, unlocked or duplicated.
- **Volkmann-Data:** This scenario contains the muscle and globe data based on Volkmann 34. In this data the pulleys are equal to the anatomical origins.
- **Orbit-Data:** This scenario contains the same original data as it is used in the Orbit™ computer system (this data can be found in the "Orbit_Norm" file of the Orbit™ computer system). This data is similar to the data stored in the pathological model with some minimally different parameters. This scenario is primary used to compare simulations done with the Orbit-Model in SEE++ with the Orbit™ computer system.
- **Pulley-Data:** This scenario contains the same data as the "Pathological Model". By default it is the active scenario and is used as source for new scenarios.

Scenarios are in a hierarchical relationship to each other. That means that a sub-scenario always depends on the data of the scenario it was created of. All scenarios are based on the data of the "Pathological Model". Scenarios in the same tree level as the "Pathological Model" represent so-called preoperative data. Surgeries can be simulated based on this data. The responsibility to define which scenario represents preoperative data lies with the user. One possible approach is to first simulate a pathology based on the pulley data, then one transfers the final result of the simulation to preoperative data and finally the surgery is simulated. At the end of the simulation the result of the surgery can again be transferred to preoperative data, for example to perform another surgery.

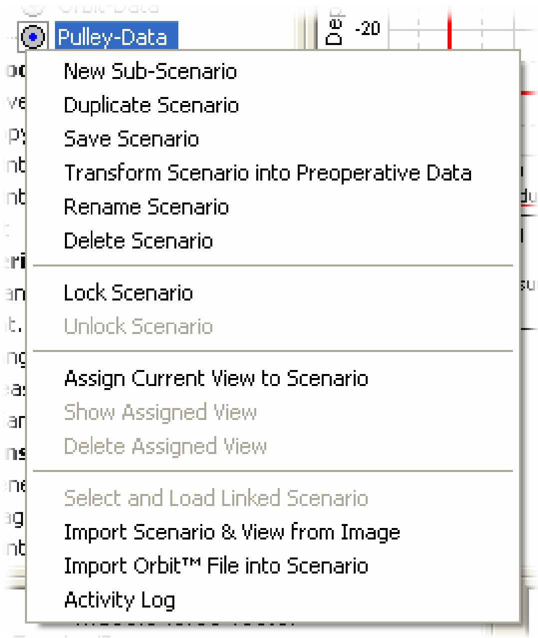
Only one scenario can be active at the same time in the program. The active scenario is marked with a small grey quadratic frame around the symbol besides the name of the scenario. The user can switch the active scenario by clicking on a scenario (name or symbol) with the left or the right mouse button. The selected scenario thereby is chosen as active scenario and loaded at the same time. If the user performs a left-click on the active scenario, it is reloaded. When loading a scenario, the medical data stored in the scenario is compared with the current data (which can be viewed via the Treeview or the main menu). If differences exist, the following warning is displayed:



If the user clicks on "Yes" or "Ja", all current changes of the medical data are discarded and are overwritten with the data from the chosen scenario. A click on "No" or "Nein" aborts the process and the scenario is not loaded as well as not set active, if it is not already active.

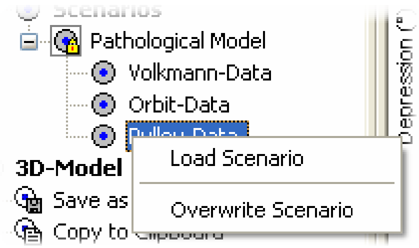
Only discard changes if you are sure that you do not need them any more. This procedure cannot always be completely undone!

If a view is assigned to a scenario, then, when loading a scenario, the assigned view is loaded together with the scenario by default (thereby the current view is overwritten). If you do not want that the assigned views are loaded automatically with a scenario, you can turn of this behaviour using the general options 141.



There exists a menu for editing scenarios, which can be displayed by right-clicking on a scenario. This menu always refers to the scenario that was clicked on with the right mouse button. That is also the reason why a scenario is loaded when clicking on it with the right mouse button.

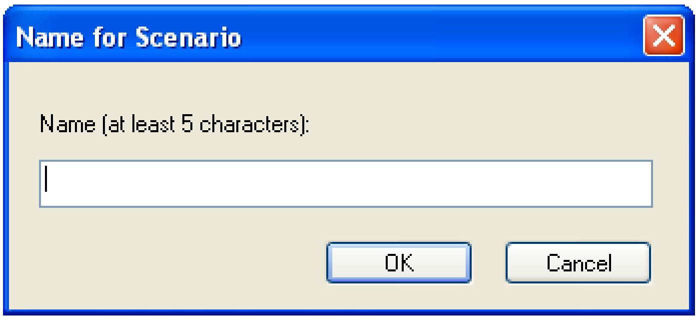
Changes to the gaze pattern of the current scenario (via the gaze pattern dialog 91) are directly saved in the scenario and do not have to (as changes to the medical data) be saved with "Save Scenario". Furthermore, the gaze pattern of locked scenarios can be changed anytime. You only have to set the scenario active and perform the desired changes via the gaze pattern dialog.



There exists an exception for this behaviour. This exception occurs when the currently selected scenario contains one or more unlocked sub-scenarios. If you click on one of this unlocked sub-scenarios with the right mouse button, a menu is displayed. This menu allows you to overwrite the sub-scenario with the currently selected scenario data. As an alternative, you can load the clicked scenario via the other menu item.

New Sub-Scenario

This menu item creates a new scenario one level beneath the selected scenario. The data for the new scenario is copied from the selected scenario. Before the new scenario is created, the following dialog is displayed:



In this dialog the name of the scenario has to be entered (at least 5 characters). When clicking the "OK" button, the new scenario is created and shown in the tree. A click on "Cancel" aborts the creation process and no new scenario is created. When creating a new sub-scenario, the scenario beneath which the new scenario is created is automatically locked and the new scenario is set active to assure the traceability of the changes in the scenarios. Sub-scenarios can also be created for locked scenarios.

If you have forgotten to create a new scenario before changing the medical data and you do not want to loose your changes and do not want to overwrite the active scenario, proceed as follows: Create a new sub-scenario based on the active scenario or duplicate it. Ignore the warning concerning unsaved changes by clicking on "No" or "Nein". After entering a name for the new scenario right-click on the new scenario and afterwards left-click on the menu item "Save Scenario". Thereby your changes of the new scenario are saved and the parent scenario is not overwritten.

Duplicate Scenario

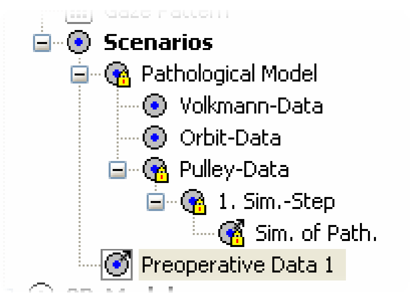
This menu item creates a copy of the selected scenario and inserts it into the level where the selected scenario is located. Before creating a new scenario the user has, just like when creating a new sub-scenario, the possibility to specify a name for the new scenario. The name of the selected scenario is automatically proposed as name for the new scenario. Scenarios on the same level as the "Pathological Model" (scenarios that contain preoperative data) cannot be duplicated. Locked scenarios can be duplicated, whereas the new scenario is not automatically locked. The newly created scenario is automatically set active.

Save Scenario

A click on the menu item "Save Scenario" saves the medical data of all three eyes to the selected scenario and overwrites all the data that was stored in this scenario before. If a scenario is locked, it cannot be saved.

Transform Scenario into Preoperative Data

If the simulation of a pathology is completed, you can create a new scenario with the help of this menu item which has some special properties. The reason for this special type of scenario is the better differentiation between the simulation of a pathology and the simulation of a surgery. The special properties of scenarios transformed into preoperative data are:



- The new scenario is always at the same level as the "Pathological Model". More precisely all scenarios at the level of the "Pathological Model" represent preoperative data. The "Pathological Model" contains preoperative data too. But there exists no scenario it was created off, because it is the global parent scenario.
- When creating a new scenario, the parent scenario is automatically locked to assure the traceability of the changes in the scenarios.
- Between the new scenario and the parent scenario a link is set up which is visualized in form of a small arrow in the upper right corner of the symbol next to the name of both scenarios (see also "Select and Load Linked Scenario").

For the new scenario (as when creating a sub-scenario) a name has to be specified.

Rename Scenario

This menu item allows you to change a scenario's name after its creation.

Delete Scenario

This menu item deletes the selected scenario and all its sub-scenarios. If the selected scenario or one of its associated sub-scenarios contains a link to preoperative data, a warning is displayed. That is because after the deletion the links of referenced preoperative scenarios to the appropriate referring scenarios are invalid. If a scenario with preoperative data is deleted, the link in the associated referring scenario is deleted too.

Lock Scenario/Unlock Scenario

When creating a sub-scenario and transforming a scenario into preoperative data, the referring scenario is automatically locked and cannot be unlocked as long as the created sub-scenario or the scenario with the preoperative data exists. The reason of this automatic lock is to assure the traceability of the changes in the scenarios. A locked scenario can be recognized by the small yellow lock icon displayed in the lower right part of the symbol next to the name of the scenario.

Scenarios that are not locked automatically can be manually locked via the menu item "Lock Scenario". This is useful to avoid changes that can be done accidentally such as overwriting through saving or through the import of Orbit-Files. The locking of a scenario does not prevent it from being deleted. Via the menu item "Unlock Scenario" a scenario can be unlocked again, if the scenario's hierarchical position allows it.

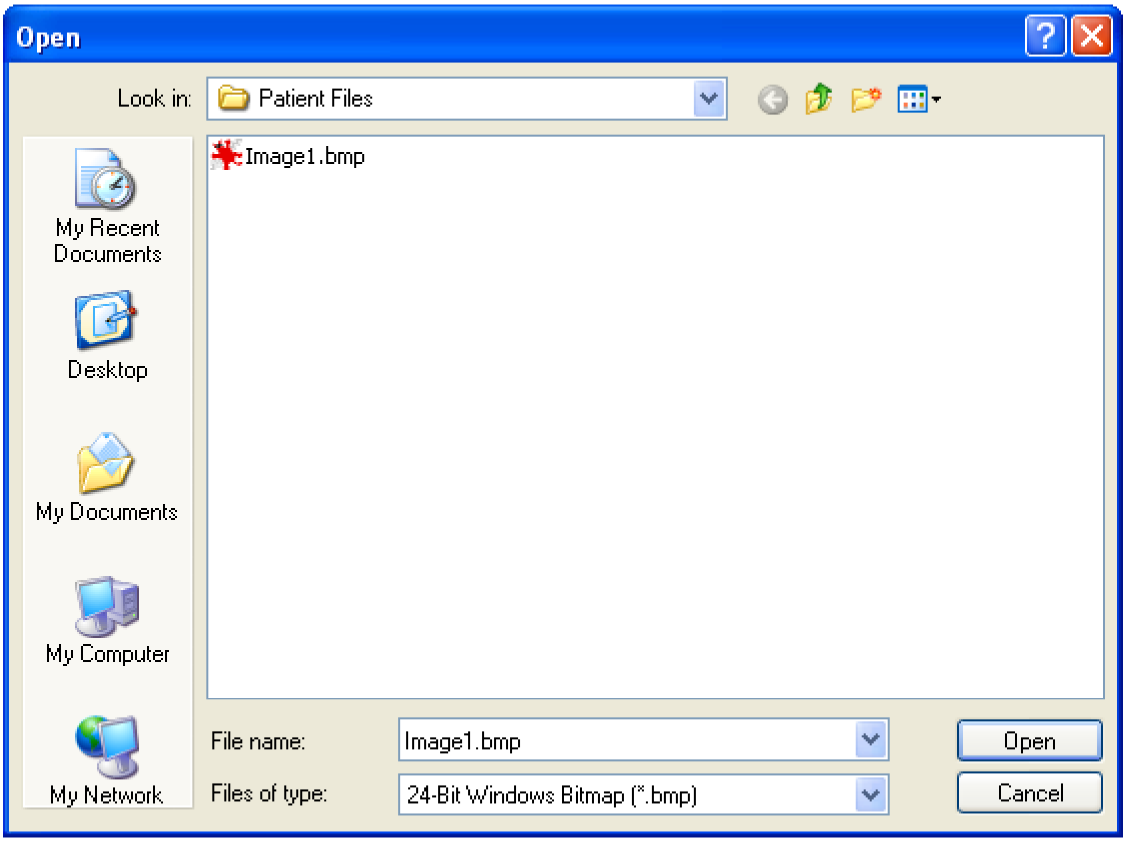
Select and Load Linked Scenario

This menu item can only be selected, if the selected scenario was created via the menu item "Transform Scenario into Preoperative Data" and the referring scenario was not deleted yet. In this case the referring scenario is selected as the active scenario and is loaded.

4.4.1 Views

You can assign a view to each scenario. To do so, use the menu item "Assign Current View to Scenario". A view is the sum of all properties you can configure for the diagrams and the 3D-model in SEE++ (see toolbar views 128). A view that has been assigned in such a way can later be loaded via the menu item "Show Assigned View". If no view is assigned to the current scenario this menu item is deactivated. Via the menu item "Delete Assigned View" you can remove an assigned view.

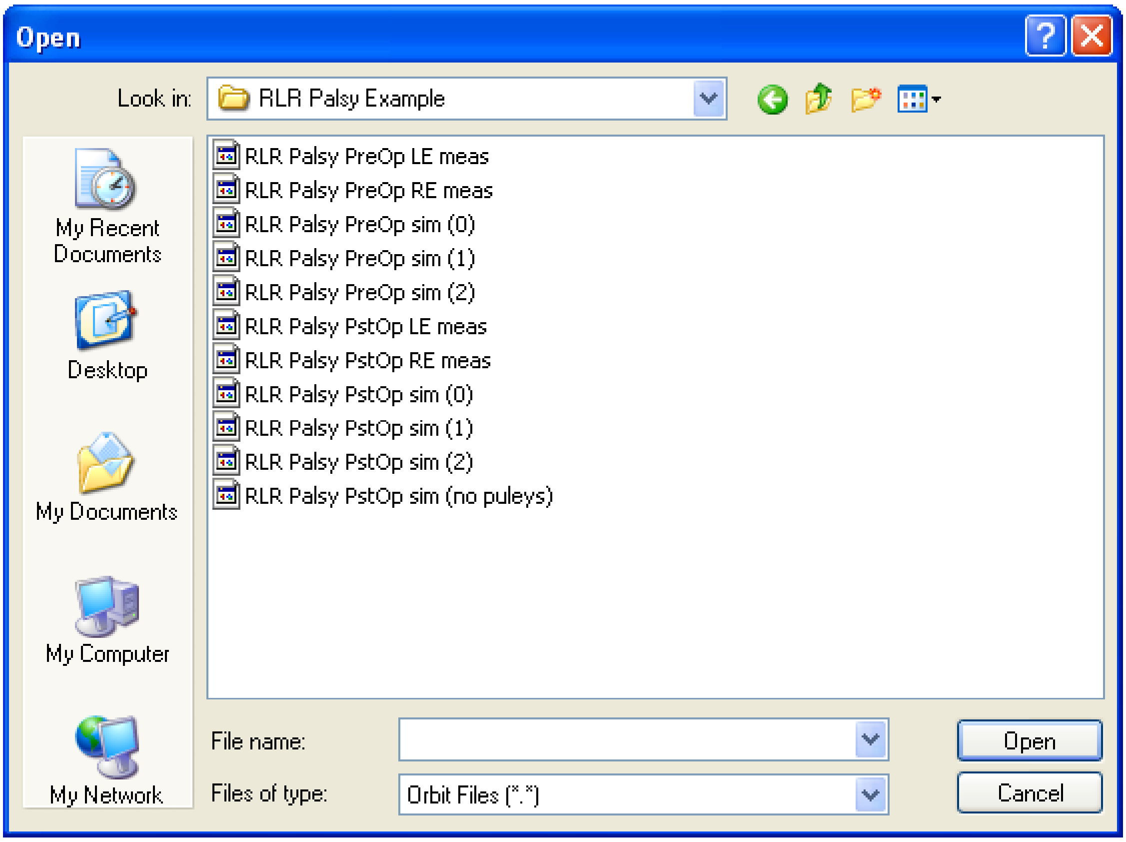
If you save an image 149 in SEE++, the current medical data 85 as well as the current view is automatically saved to the meta information of the image. Via the menu item "Import Scenario & View from Image" you can import the data of such an image into the currently selected scenario. The imported view is assigned to the scenario and is displayed directly after the import. All data which has previously been stored in the selected scenario is lost during this process!



After clicking on the menu item "Import Scenario & View from Image" and confirming the warning message with "Yes" or "Ja", the dialog for selecting the image file is displayed. You can choose between images in bitmap format (.bmp) and JPEG format (.jpg). Navigate to the particular directory and click on the image file you want to load. Afterwards click on the "Open" or "Öffnen" button to load the file. If you push the "Cancel" or "Abbrechen" button, no file is loaded and the current scenario is retained unchanged.

4.4.2 Import Orbit-Files

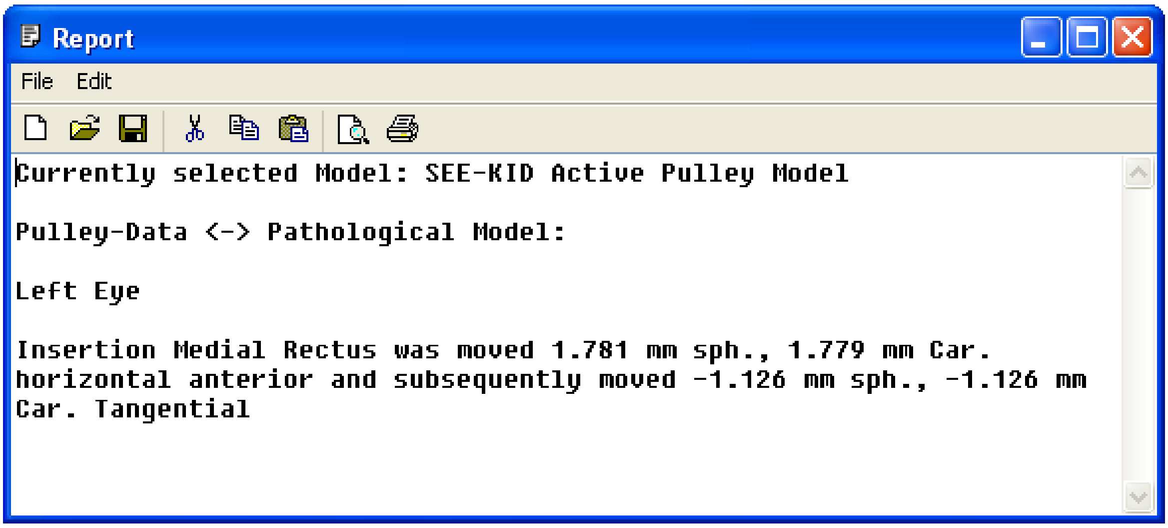
With this function you can import a complete patient file from the Orbit™ program into a scenario of SEE++. After selecting the menu item "Import Orbit™ File into Scenario" a warning is displayed, that the import overwrites all data of the selected scenario. If you accept the warning by clicking on "Yes" or "Ja", the following dialog is displayed:



Navigate to the directory, where the file to import is located, select the appropriate file and click on the "Open" or "Öffnen" button. If you have chosen a valid file, you are asked, if you want to import the patient data too. By selecting "Yes" or "Ja" the existing patient data in SEE++ is overwritten.
Afterwards, SEE++ tries to import the appropriate data for all three eyes (left eye, right eye, reference eye) and then displays for which eyes it was able to import the data. This completes the import process.

4.4.3 Activity Log

The activity log offers the possibility to display a textual list of all changes made between two scenarios from the selected scenario down to the "Pathological Model". When going through the scenarios to the "Pathological Model" the links of the preoperative data to their particular referring scenario are considered too. After transposing the insertion of the left medial rectus muscle and afterwards saving the modification in the scenario "Pulley-Data", the activity log looks as follows:



You do not have to save the changes in a scenario to access the activity log. If there are changes, that are not saved in the currently active scenario yet, a comparison of the current medical data ("Current Data") and the data stored in the selected scenario is displayed in the activity log first.
The report window is an adequate text editor similar to the enclosed Microsoft Windows® editor.

4.5 Reference Data

The SEE++ simulation model [51] simulates the oculomotoric system via a biomechanical model consisting of two eyes and a "virtual" reference eye. This virtual reference eye specifies for the whole simulation how a "normal" or healthy eye is working. This affects the definition of the geometry, the force development behaviour of the eye musculature and the innervation of the brainstem. The sum of all this parameters forms the abstract entity of a simulated eye. Now the parameter differences related to the reference eye are calculated throughout the simulation to determine a pathological reaction of the fixing or following eye. An completely healthy oculomotoric system only works in SEE++, if the values for all parameters of all three eyes including the "virtual" reference eye are the same. This is always the starting position for the execution of a simulation in SEE++ [20].

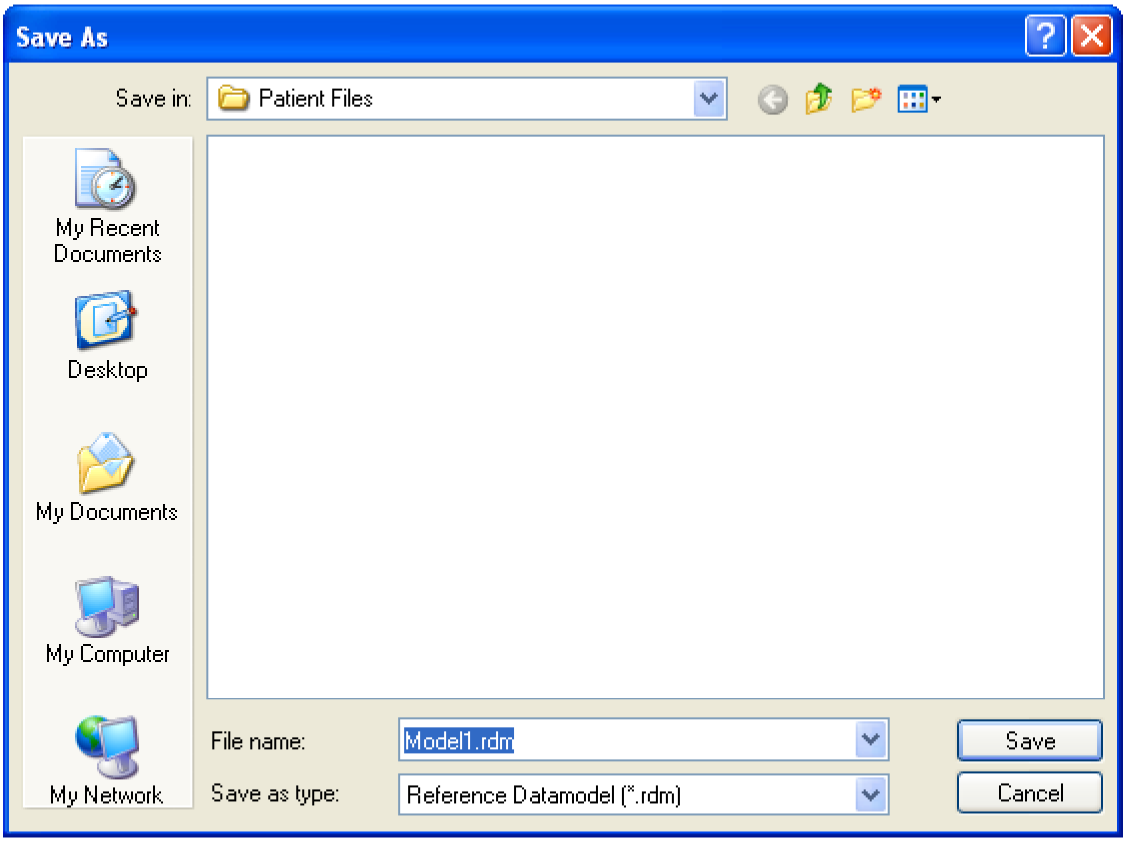
In some cases it can be necessary to change these default configurations. For this reason it is possible to save all medical data [85] of an eye as reference data to a file. Only values important for the simulation and no patient specific data are stored. In a second step existing parameters can be loaded from a saved reference data file into one or even all three abstract eyes. If you for example want to use different measured data for the geometry or the muscle function, you can store these values with the aid of a separate reference data model and import them for a simulated patient if required.

All functions for the export (saving) and import (loading) of reference data can be found in the main menu under "Reference Data->Export" [106] and "Reference Data->Import" [107].

4.5.1 Export

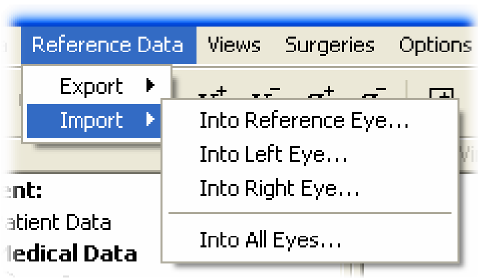
The export of reference data allows you to save the whole parameter set of an eye into a reference data file. Via the menu item "Reference Data->Export" you can select from which eye you want to save the data into a file.

After selecting an item the dialog to save a file is displayed.



Navigate to the desired directory and name the file appropriately. Reference data files have the extension ".rdm". Click on the "Save" or "Speichern" button to save the file. If you select "Cancel" or "Abbrechen", the file is not saved and no reference data is exported.

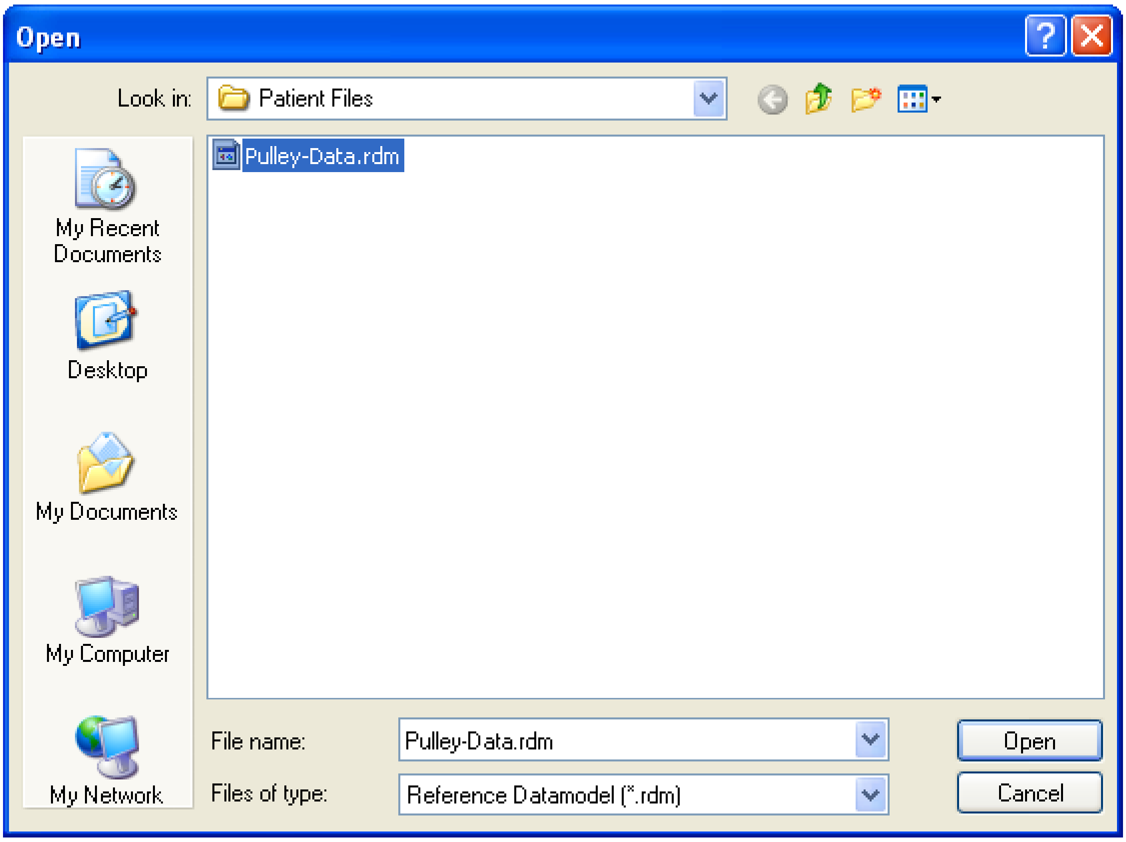
4.5.2 Import



The import of reference data loads a saved reference data file into a selected eye. Thereby the eye where the reference data is loaded to is **not** depending on the eye the data was saved from. In this menu you can import a reference data file into one of the three eyes or even fill all three eyes with the same data at once.

If the option "Into All Eyes..." is used, a new definition of a "healthy" oculomotoric system is specified, which forms a new basis on which pathological situations through the changing of specific parameters can be simulated.

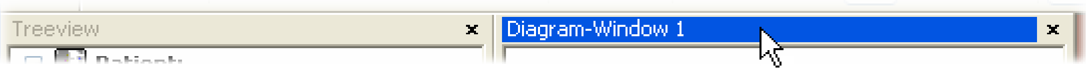
After selecting a menu item the dialog to open a file is displayed.



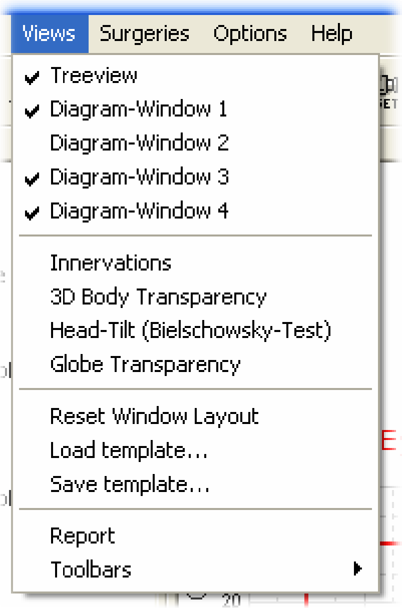
Navigate to the appropriate directory, where the file you want to import is located. Select the file to import and confirm the dialog via the "Open" or "Öffnen" button. If you push the "Cancel" or "Abbrechen" button, no file is loaded and the previous values are retained unchanged.

4.6 Views

As already explained in the introduction SEE++ offers four so-called diagram-windows to display different diagrams. In each diagram-window any diagram can be shown (muscle force distribution diagram 115, muscle force vector diagram 115, Hess-diagram 116, squint-angles diagram 117, Stateviewer 118).



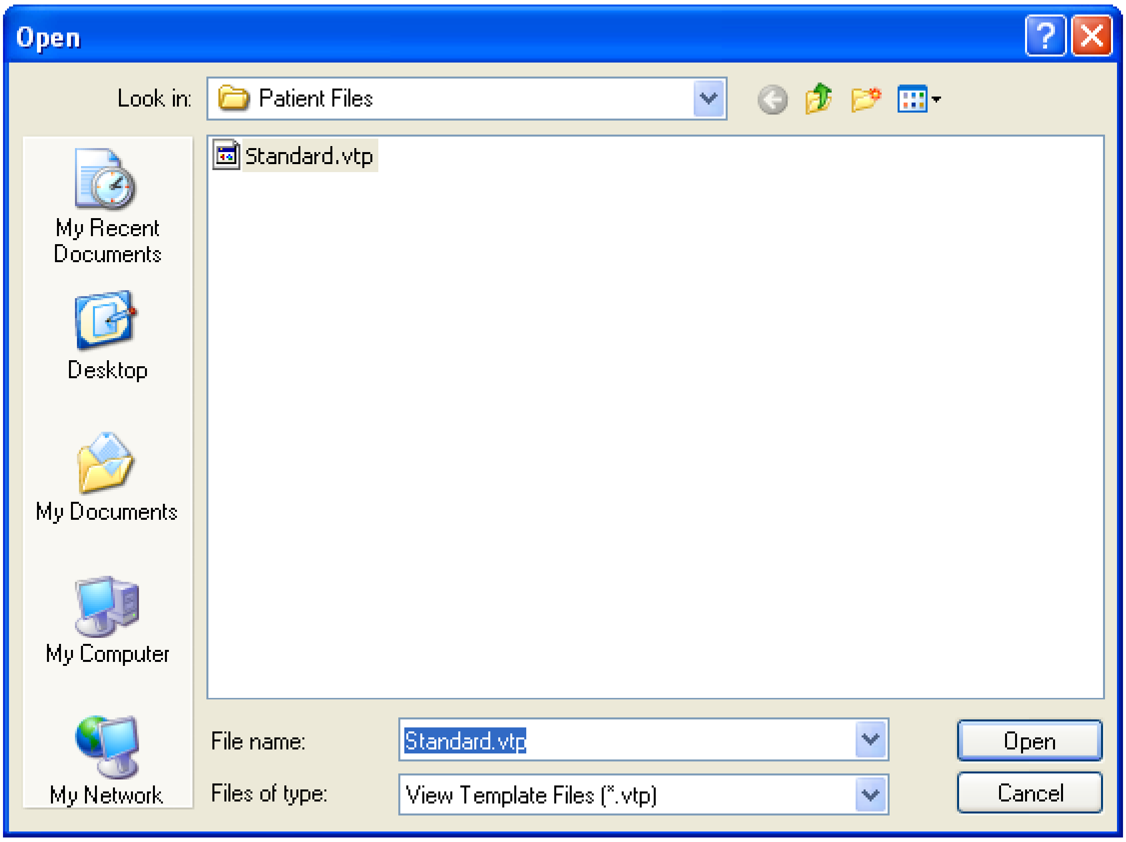
By default all diagram-windows and the Treeview are directly connected to the main window (docked). If you left-click on the title bar (the name of the window is displayed there too) in the upper or left region of the window, hold the mouse button down and pull it aside at the same time, you can pull out the window from the main window frame and position it as a separate window anywhere you like. With a click on the small "X" in the right or upper region of the title bar the window can be hidden. You can hide all windows and toolbars so that only the 3D-view 111 is displayed. The 3D-view cannot be hidden.



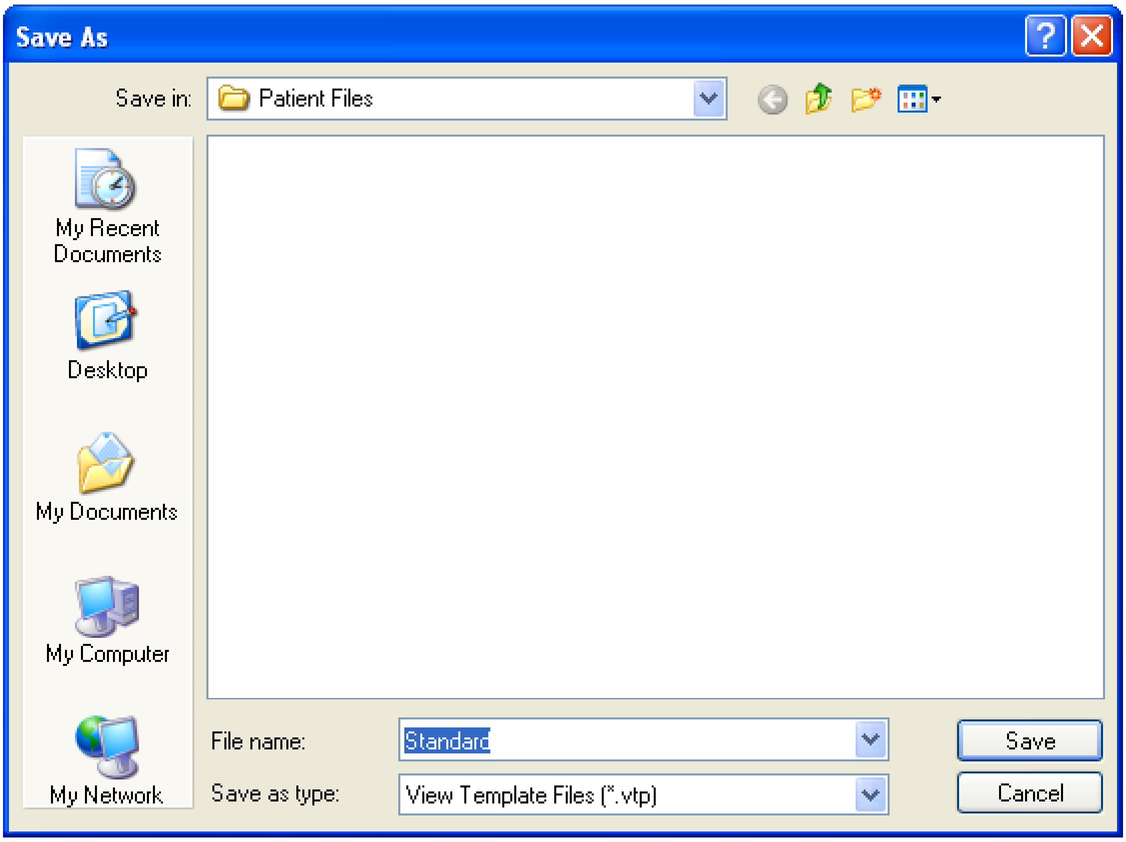
In order to show a hidden window use the menu items "Treeview" and "Diagram-Window 1-4" in the menu "Views". Those menu items are used to hide and show the appropriate window. The next four menu items are used to hide and show the windows for the innervations 121, for the configuration of the 3D body transparency, for the modification of the head-tilt as well as for the configuration of the globe transparency.

The function "Reset Window Layout" resets the layout of the toolbars, the size of the Treeview and of the different diagram-windows, the therein displayed diagrams as well as the visibility of each window to the default settings. Via the menu item "Load template..." you can load a view template (.vtp), that was previously saved via the menu item "Save template...". The view settings of the toolbars, the size of the Treeview and of the different diagram-windows, the therein displayed diagrams as well as the visibility of each window are saved in a view template.

After selecting the menu item "Load template..." the dialog to open a file is displayed.



Navigate to the appropriate directory, where the file you want to load is located. Select the file to load and confirm the dialog via the "Open" or "Öffnen" button. If you push the "Cancel" or "Abbrechen" button, no file is loaded and the current settings are preserved.
After selecting the menu item "Save template..." the dialog to save a file is displayed.



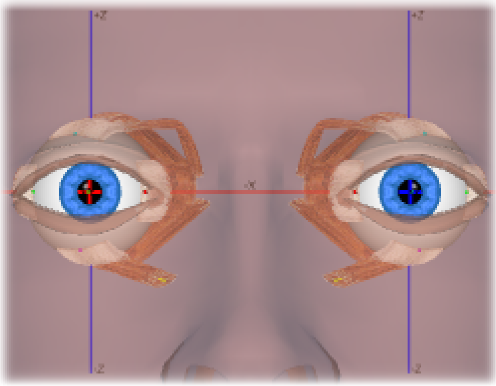
Navigate to the desired directory and name the file appropriately. View templates have the extension ".vtp". Click on the "Save" or "Speichern" button to save the file. If you select "Cancel" or "Abbrechen", the file is not saved and no view template is saved.

Finally via the menu "Views" the report 158 can be displayed and the toolbars 120 can be hidden or shown.

4.6.1 3D-View

By default the 3D-view displays the left eye and the right eye as well as a 3D representation of the human body. All elements displayed in the 3D-view such as the body, the muscles of each eye etc. can be changed via the main functions toolbar 121 and via the 3D-view options toolbar 124. In the 3D-view only one eye can be set as the active eye. The active eye can be recognized by the blue cornea marker, if it is enabled. To switch the active eye you can either use the 3D-view options toolbar 124 or the tabulator key. When changing the gaze direction and when transposing an insertion the active eye is automatically set to the selected eye (in the following picture the left eye is set as the active eye).

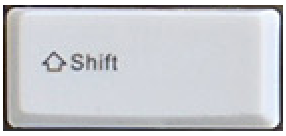
Navigation in the 3D-View with the Mouse

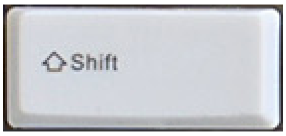


While navigating with the mouse, first always click into the 3D-view with one mouse button, keep the button pressed down and then move the mouse while still pressing the mouse button. Simply release the mouse button to stop.

Mouse Button	**Action**
Left mouse button not on a muscle insertion	Rotate the whole 3D-view (camera rotation) with the help of a "virtual hemisphere". During the rotation the border of the hemisphere is displayed as a black circle. Within this sphere the rotation is done around the x- and z-axes and outside around the y-axis.
Left mouse button on a muscle insertion	Transpose a muscle insertion according to the chosen surgery 133.
Double-click with the left mouse button on a muscle insertion	Opens the muscle data dialog 86 and displays the tab sheet of the selected muscle.
Rotate the mouse wheel *or*  + left mouse button	Zoom in or zoom out the whole 3D-view (zoom function).
Click the mouse wheel *or* the middle mouse button	Reset the 3D-view to the initial position (camera reset).
Double-click with the mouse wheel *or* the middle mouse button	Reset the 3D-view to the initial position (camera reset) and reset both eyes to the primary position (eye positions reset).
Right mouse button on a globe	Change the gaze direction of the chosen eye.
Right mouse button not on a globe	Move the whole 3D-view (at the beginning of the movement the 3D-view is automatically reset).

Navigation in the 3D-View with the Keyboard

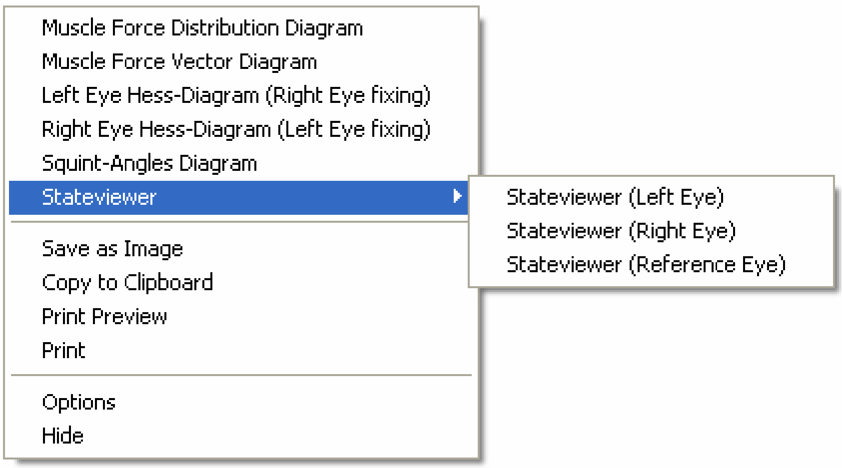
Key	Action
	Switch the active eye.
	Change the gaze direction of the active eye 5° upwards.
	Change the gaze direction of the active eye 5° downwards.
	Change the gaze direction of the active eye 5° to the left.
	Change the gaze direction of the active eye 5° to the right.
 + one of the 4 keys above	Change the gaze direction of the active eye 0.5° into the appropriate direction.
 *or* 	Rotate the whole 3D-view around the x-axis of the "virtual hemisphere" upwards.
 *or* 	Rotate the whole 3D-view around the x-axis of the "virtual hemisphere" downwards.
 *or* 	Rotate the whole 3D-view around the z-axis of the "virtual hemisphere" to the left.
 *or* 	Rotate the whole 3D-view around the z-axis of the "virtual hemisphere" to the right.
 *or* 	Reset the 3D-view to the initial position (camera reset).

	Zoom in the whole 3D-view (zoom function).
	Zoom out the whole 3D-view (zoom function).
	While transposing the insertion point of a muscle with the mouse, you can abort the transposition by pressing this key. The insertion point is reset to its initial position.
	Change the head-tilt for the simulation of the Bielschowsky-Test 5° to the right (in the direction of the right shoulder).
	Change the head-tilt for the simulation of the Bielschowsky-Test 5° to the left (in the direction of the left shoulder).
 + one of the 2 keys above	Change the head-tilt for the simulation of the Bielschowsky-Test 1° into the appropriate direction.

You can visualize the globe translation 29 in the 3D-view. To do so, select "Options->Globe Translation" in the main menu.

4.6.2 Diagrams

The eight diagrams in SEE++ have certain similarities. One similarity is that per diagram-window only one diagram can be displayed at a time. Furthermore, you can display the following menu by right-clicking into one of the diagram-windows:

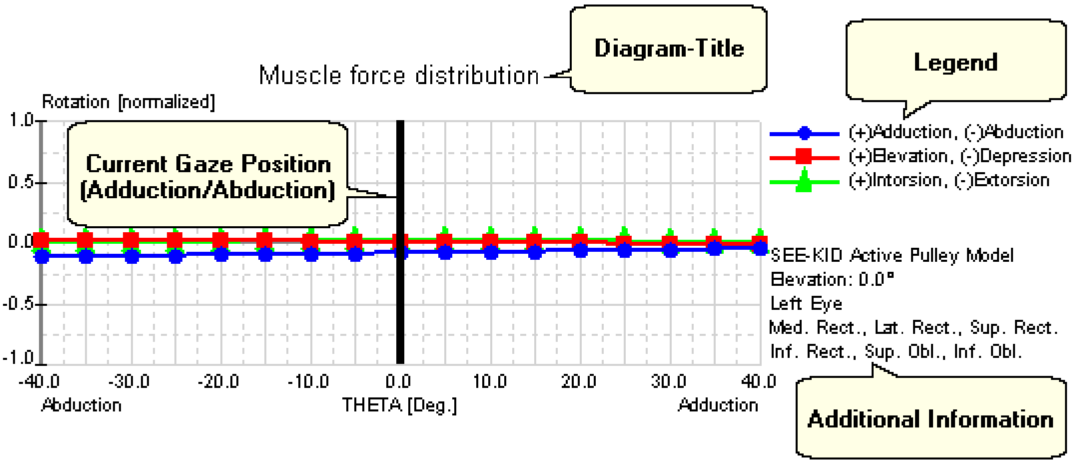


The first six menu items are used to display the appropriate diagram in the selected diagram-window. If the diagram is already displayed in the selected diagram-window, it cannot be selected. If the selected diagram is already displayed in another diagram-window, it is hidden in the diagram-window where it was displayed before and is displayed in the new window.

Diagrams can be copied to the clipboard or saved as an image (bitmaps or JPEGs). For this purpose read the information on how to save diagrams as an image149. Furthermore, diagrams can be displayed in the print preview and can be printed. You can find further information in the chapters about the print preview158 and about printing157. Via the menu item "Options" you can edit the diagram settings144. The menu item "Hide" is used to hide the whole diagram-window including the displayed diagram.

4.6.2.1 Muscle Force Distribution

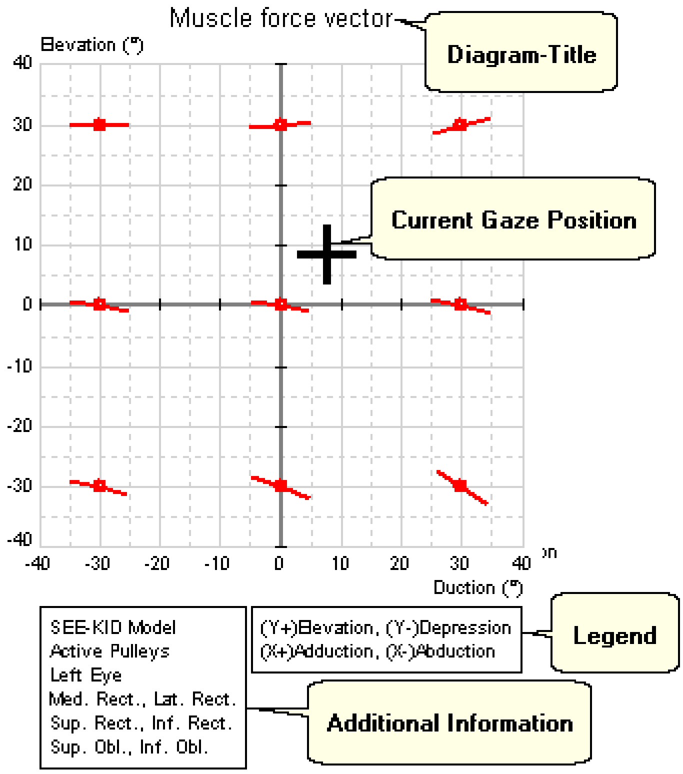
The muscle force distribution diagram is a geometric diagram. You can find further information concerning the mathematical background in the chapter about geometric models33. The following picture shows a short overview of the specific parts of the diagram:



The additional information states the active model as well as the displayed elevation plane and the appropriate eye with its muscles, which the diagram currently comprises. Within the diagram the adduction/abduction of the current gaze direction for the eye selected in the diagram is displayed in the form of a line. When you left-click on the line with the mouse and then move the mouse across the diagram while still pressing the mouse button, the gaze direction in adduction/abduction can be modified.

4.6.2.2 Muscle Force Vector

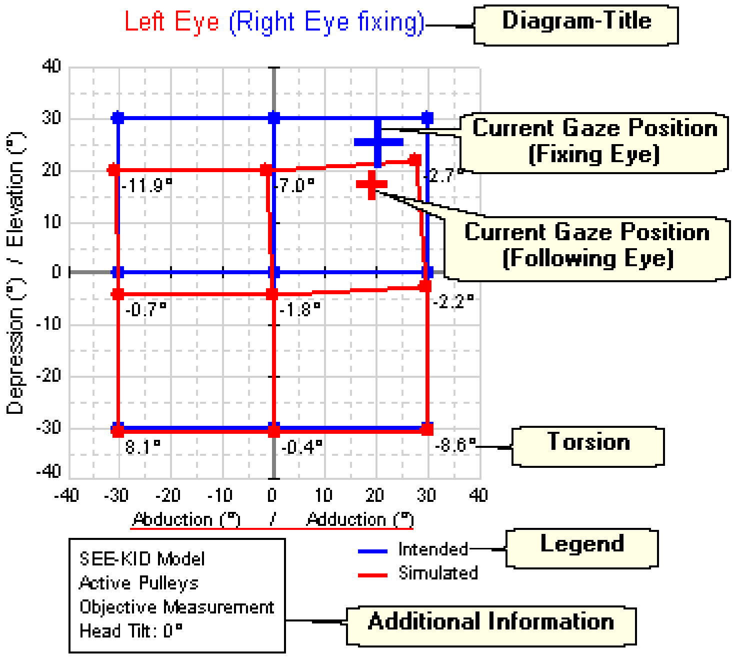
Similar to the muscle force distribution diagram in the muscle force vector diagram the specific rotational components of the rotation axis of the globe are displayed as direction vectors depending on the displayed muscles. The following picture displays a short overview of the specific parts of the diagram:



The additional information states, similar to the muscle force distribution diagram, the active model as well as the appropriate eye with its muscles, which the diagram currently comprises. Within the diagram the current gaze direction (adduction/abduction and elevation/depression) for the eye selected in the diagram is displayed in the form of a cross. When you left-click on the cross with the mouse and then move the mouse across the diagram while still pressing the mouse button, the gaze direction can be modified.

4.6.2.3 Hess-Diagram

There exist two Hess-diagrams in the SEE++ program: one for the left eye with the right eye fixing and one for the right eye with the left eye fixing. Details concerning the functionality of the Hess-Test can be found in the chapter Hess-Lancester-Test 47. The following picture displays a short overview of the specific parts of a Hess-diagram:

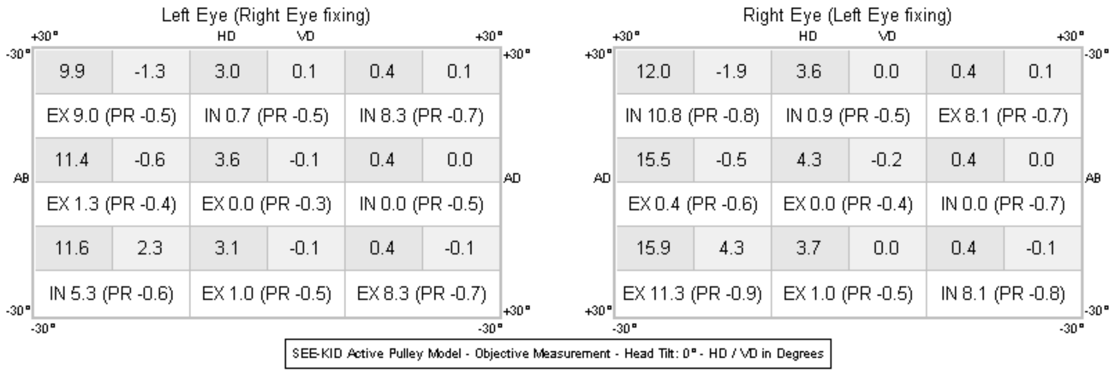


Within the diagram the current gaze direction (adduction/abduction and elevation/depression) for the fixing eye (if the right eye is fixing the right eye and if the left eye is fixing the left eye) is displayed in the form of a blue cross. This cross is only visible if the appropriate eye is the current active eye in the 3D-view. If the option "Following Eye" 122 is activated, the gaze direction of the following eye is also displayed in the form of a red cross. When you left-click on the blue cross with the mouse and then move the mouse across the diagram while still pressing the mouse button, the gaze direction can be modified. If you navigate the mouse above a blue, red or green point in the diagram, the coordinates of this point are displayed in a small window as well as in the status bar. By double-clicking on a blue fixation point in the Hess-diagram you can change the fixation position as well as the fixing eye according to the selected point.

The displayed torsions depend on the currently set type of torsion measurement. By default the torsion values in the Hess- and Squint-Angles diagrams are always displayed as objectively measured values. However, you can switch to subjective torsion values (cyclo-deviation) via the main menu under "Options->Subjective Torsion Measurement" anytime. Further information concerning the different kinds of torsions can be found in the chapter simulation 53.

4.6.2.4 Squint-Angles Diagram

In principle the squint-angles diagram is simply a different display format for the Hess-diagram. However, in the squint-angles diagram the left eye with right eye fixing and the right eye with left eye fixing are displayed at the same time. Depending on the size of the diagram-window, both fixations are positioned side by side or one below the other. More detailed information concerning the squint-angles diagram can be found in the chapter simulation 51. The following picture displays a squint-angles diagram with both fixations positioned side by side:



The deviations in the squint-angles diagram can be displayed either in degrees or in prism diopters. The selected unit for the deviations, the active model, the current type of torsion measurement (objective or subjective) as well as the current head-tilt are displayed in the lower region of the diagram (additional information box). If you double-click on a gaze direction (HD, VD or torsion of a gaze direction) in one of the two fixations, the fixation position as well as the fixing eye are modified according to the selected gaze direction.

The displayed torsions depend on the currently set type of torsion measurement. By default the torsion values in the Hess- and Squint-Angles diagrams are always displayed as objectively measured values. However, you can switch to subjective torsion values (cyclo-deviation) via the main menu under "Options->Subjective Torsion Measurement" anytime. Further information concerning the different kinds of torsions can be found in the chapter simulation53.

4.6.2.5 Stateviewer

The Stateviewer can be displayed for all three eyes (left eye, right eye, reference eye) and is rather addressed to experienced users, who want to get into the specific (internal) parameters of the model in detail. Depending on whether the selected eye is currently the fixing or the following eye, the displayed parameters are calculated according to the current fixation. The parameters shown in the Stateviewer are summarized and grouped on different tab sheets. Select the desired tab sheet by clicking on the appropriate heading with the left mouse button. The following tab sheets are available:

- **Patient**
- **Head Position and VOR** (vestibulo ocular reflex)
- **Eye Position and Torsion**
- **Muscle Geometry**
- **Muscle Forces**
- **Innervations**

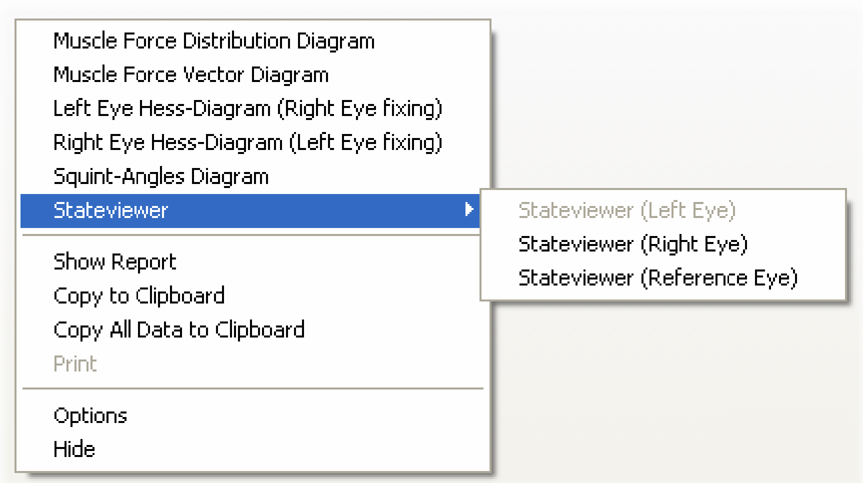
Furthermore, on each tab sheet the current eye position of the selected eye is displayed in Fick coordinates. If the appropriate eye is currently fixing or following is also displayed.

Patient | Head Position and VOR | Eye Position and Torsion | Muscle Geometry | Muscle Forces | Innervations

Left (Fix.) Eye (0.00/0.00/0.00) Fick Coordinates (+Elevation,+Adduction,+Intorsion)

Name: Left Eye	Unit:	MR	LR	SR	IR	SO	IO
Anatomic Origin:	(mm) (x/y/z)	-17.0/-30.0/1.0	-13.0/-34.0/-1.0	-15.0/-31.8/3.6	-17.0/-31.8/-2.4	-18.0/-31.5/5.0	-13.0/8.0/-15.5
Pulley (Functional Origin):	(mm) (x/y/z)	-13.0/-6.0/0.1	13.0/-6.0/0.3	-4.5/-6.0/13.0	-4.5/-6.0/-13.0	-15.3/8.0/11.8	-13.0/8.0/-15.5
Pulley Displacement:	(mm) (+Ant./-Post.)	0.0	0.0	0.0	0.0	0.0	0.0
Insertion:	(mm) (x/y/z)	-9.6/8.8/0.0	10.1/6.5/0.0	2.8/6.5/10.3	1.8/6.9/-10.2	2.9/-8.0/8.8	8.0/-9.2/0.0
Muscle Radius:	(mm)	13.087	11.994	12.426	12.429	12.256	12.177
Arc of Contact:	(mm)	9.9	5.1	6.5	6.3	7.9	16.2
Tendon Length:	(mm)	4.9	7.7	5.4	4.8	31.9	1.3
Tendon Width:	(mm)	10.5	9.3	10.8	10.0	10.8	8.6
Muscle Length (L0):	(mm)	31.9	37.5	33.8	35.6	34.2	30.6
Muscle Length Change:	(%/L0)	10.101	15.923	14.839	13.702	-3.086	7.590
Sideslip Scaling:	(%/100)	0.270	0.155	0.000	0.160	0.000	0.010
Passive (elastic) Strength:	(%/100)	1.0	1.0	1.0	1.0	1.0	1.0
Active (contractile) Strength:	(%/100)	1.0	1.0	1.0	1.0	1.0	1.0
Relative Passive Strength:	(%/100) LR	1.040	1.000	0.800	0.940	0.410	0.380
Relative Active Strength:	(%/100) LR	1.040	1.000	0.690	0.940	0.410	0.380
Globe Rotation Axis:	(x/y/z)	0.131/-0.247/-0.960					
Muscle Force Distribution:	(%/100) (+Add./-Abd.)	1.00	-1.00	0.07	0.12	-0.39	-0.28
	(%/100) (+Ele./-Dep.)	0.01	0.01	0.87	-0.90	-0.64	0.72
	(%/100) (+Int./-Ext.)	0.01	-0.02	-0.49	0.41	-0.66	0.63

For copying data from the Stateviewer to the clipboard, simply select the desired area with a left-click while at the same time pulling the mouse within the parameter table. Then right-click into the diagram-window and choose "Copy to Clipboard". The selected parameters are copied to the clipboard in **textual** form (not as an image like when copying the other diagrams!) and can be pasted in any word processing or spreadsheet program (e.g. Word® or Excel®) for further usage. If you want to copy all parameters of all tab sheets at the same time to the clipboard, then right-click into the diagram-window where the Stateviewer is shown (it does not matter which tab sheet is currently active) and select the menu item "Copy All Data to Clipboard". The data is then copied to the clipboard in textual form and in the order of the tab sheets (from left to right).



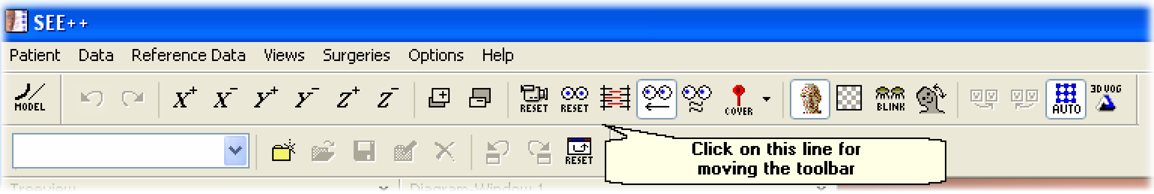
In order to print the data of the Stateviewer you have to proceed in a different way as in the other diagrams. You cannot print the data of the Stateviewer directly from within the diagram-window. You have to display the data in form of a report first. To do so right-click into the diagram-window and choose "Show Report". Then the same window like for the activity log 104 or like for the normal report 158 is opened, but with the content of all tab sheets of the currently displayed Stateviewer in textual form. Via the report window you can now print the desired data (if you do not want to print some of the parameters, you can simply delete those like with a common text editor). It is not possible to save the Stateviewer as an image, but you can display the parameters as a report and then save the report as a text file.

4.7 Toolbars

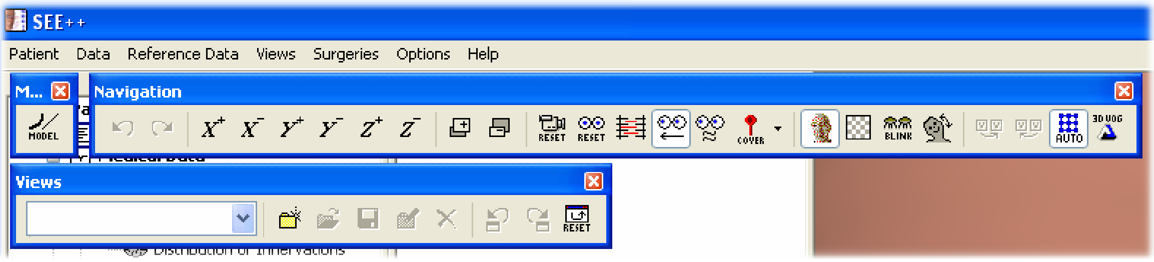
The SEE++ system provides toolbars for using the most important functions of the program fast and easy. There exist four different toolbars in the program:

- Models 120 - is used to switch between the specific models 26
- General functions 121 (navigation) - is used for rotation, scaling and 3D-view settings
- 3D-view options 124 (globe and muscles) - is used for the configuration of the 3D-view
- Views 128 - is used for the management of different views

By default all toolbars are directly connected to the main window of SEE++ (docked).



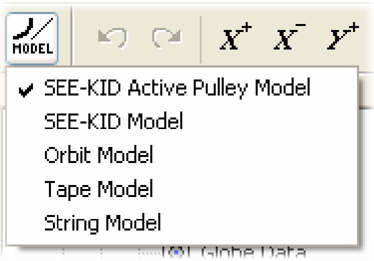
If you left-click on one of the toolbars between two symbols without activating a function and you keep the mouse button pressed down while pulling it aside at the same time, you can pull out the toolbar from the main window frame. Now you can position the toolbar as a separate window anywhere you like, as it is shown in the following image.



4.7.1 Models

The toolbar for models consists of only one element to switch between the different simulation models 26.

Left-click on the  button to open the menu providing the selection of the different available models. Additionally, you can reach this function via the main menu under "Options->Simulation Models".



By default the SEE-KID Active Pulley Model is used. Furthermore, it is possible to use the SEE-KID Model (with static pulleys), the Orbit™ Model or one of the two solely geometric models (Tape Model, String Model) (see also mathematical models 79).

If you switch to a different model, the parameters of the current patient are not changed. Only the simulation result is recalculated and possibly shows a different prognosis due to model differences. Please notice that the solely geometric models (Tape Model, String Model) do not allow Hess-Lancaster simulations, because they have no force model.

4.7.2 General Functions

The "General Functions" toolbar provides the most important navigation and viewing functions.

Use this button to undo changes made to the medical data (globe data 85, muscle data 86, distribution of innervations 89, motor fusional ability 90). You can undo up to 20 changes. You can also access this function via the main menu under "Data->Undo".

Use this button to restore previously undone changes made to the medical data. Up to 20 changes can be restored. You can also access this function via the main menu under "Data->Redo".

After clicking on one of the two buttons, a dialog with the appropriate changes is displayed. If you confirm the dialog with "OK", the changes are applied. You can turn off this dialog via the general options 141. If you do so, the changes are applied immediately without asking.

Use the following buttons to modify the visualization of the 3D-view:

Use these two buttons to rotate the 3D-view around the horizontal x-axis (above or beneath).

Use these two buttons to rotate the 3D-view around the forward pointing y-axis (skew to the right or to the left).

Use these two buttons to rotate the 3D-view around the vertical z-axis (left or right).

Use these two buttons to zoom in or to zoom out the 3D-view (zoom function).

This button resets the 3D-view to its initial position (camera reset). This affects only the current rotation, translation and zoom of the view. Resetting the view does not cause a change of the simulation parameters. You can also access this function via the main menu under "Options->Reset Camera-Rotation".

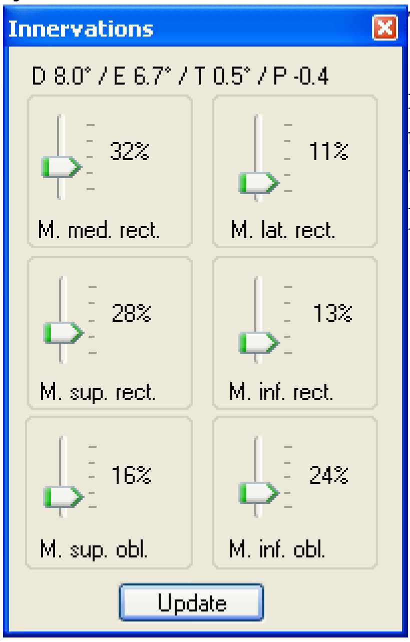
This button resets both eyes to the primary position (eye position reset). You can also access this function via the main menu under "Options->Reset Gaze-Rotations".

Further possibilities to modify the visualization of the 3D-view can be found in the chapter "3D-View" 111.

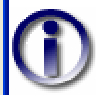
Innervations Dialog

The innervations dialog provides the possibility to manually adjust the specific activation potentials of the muscles in percentage. You can access this dialog via the main menu under

"Views-> Innervations" or via the "General Functions" toolbar by clicking on the innervations symbol .



The innervations dialog assigns a slider in the range from 0% to 100% to each muscle. The maximum deflection of a slider means that the muscle is maximally innervated. Depending on the current simulation, the eye position of the fixing eye 111 in the 3D-view is calculated. If the following eye is activated, its position is also calculated.



The innervations dialog provides the possibility to manually set the eye position without considering the law of pairwise innervation (Sherrington). If you want to know, how the distribution of innervations in a specific gaze position of the fixing eye in the 3D-view looks like, you have to push the "Update" button.

The sliders are adapted in consideration of the innervations of the agonistic and the antagonistic muscles. This obviously results into a different position of the sliders compared to the manual positioning, which is carried out without considering the law of the reciprocal innervations. Therefore, there exists no unambiguous mapping between an innervation pattern of all six muscles and an eye position.

Furthermore, the upper corner of this dialog displays the gaze position defined via the current innervation pattern. "D" stands for adduction/abduction, "E" for elevation/depression, "T" for intorsion/extorsion and "P" for protrusion/retraction. "D", "E" and "T" are declared in degrees and "P" is declared in mm. The algebraic signs are defined as described in the chapter "geometric models" 28.

Following Eye 

The button "Following Eye" switches the calculation of the eye position of the following eye in the 3D-view on or off. That means, that when the currently fixing eye (blue cross 111) is moved into a new position, the position of the currently following eye (red cross 111) is also calculated with respect to the current simulation parameters. You can switch the following eye on or off by clicking on the symbol in the "General Functions" toolbar or via the main menu under the menu item "Options->Following Eye".

Interpolation for Real-Time Assessment 

With this button you can switch the interpolation mode for the real-time assessment on or off. Further information concerning this function can be found in the chapter "Interpolation for Real-Time Assessment" 130. You can also access this function via the main menu under "Options->Interpolation for Real-Time Assessment".

Cover Test 

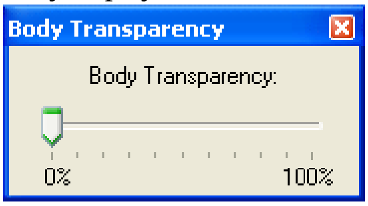
With this button you can switch the simulation of the cover test on or off. Further information concerning this function can be found in the chapter "Cover Test" 131.

3D Body 

The "3D Body" button allows to show or hide the body displayed in the 3D-view. You can also access this function via the main menu under "Options->3D Body".

3D Body Transparency 

This symbol allows to open the dialog for the configuration of the 3D body transparency of the body displayed in the 3D-view.



With this dialog you can interactively change the transparency of the body displayed in the 3D-view. 100% transparency is equivalent to switching off the displayed 3D body. You can also access this dialog via the main menu under "Views->3D Body Transparency".

Blinking 

With this button you can switch the blinking on or off. This function is only available, if the 3D body is displayed and the OpenGL™ graphic acceleration is activated (see general options 141). This function has no influence on the simulation result. You can also switch the blinking on or off via the main menu under "Options->Blinking".

Head-Tilt (Bielschowsky-Test) 

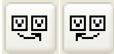
This button opens the dialog to set the head-tilt.

If you change the head-tilt, the current tilt is visualized in the 3D-view and is also used for the simulation of the Hess-Lancester test. By changing the head-tilt the so-called Bielschowsky-Test can be simulated.

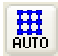
During this test the patient tilts his head in the direction of the left or the right shoulder to stimulate the vestibulo ocular reflex (VOR). Thereby, the intorsion of the eye on the side to which the head was tilted is amplified and accordingly the extorsion of the other eye is amplified as well.

The button "Reset..." within the dialog resets the head-tilt back to 0°. You can also access this dialog via the main menu under "Views->Head-Tilt (Bielschowsky-Test)".

The selected head-tilt remains set until it is changed again in this dialog! The functions "Reset View", "Reset Window Layout", "Reset Camera-Rotation", "Reset Gaze-Rotations" and the loading of any view does not reset the head-tilt! Solely the function "Reset All Settings" in the general options 141 also resets the head-tilt back to 0°.

Adjust Size of Hess-Diagrams 

With this button you can adapt the size of the diagram-window, where the Hess-diagram for the right eye (left eye fixing) is displayed, to the size of the diagram-window, where the Hess-diagram for the left eye (right eye fixing) is displayed and vice versa. These buttons are only active, if both Hess-diagrams are currently displayed and both diagram-windows, where the Hess-diagrams are displayed, are docked to the main window.

Autosize Hess-Diagrams 

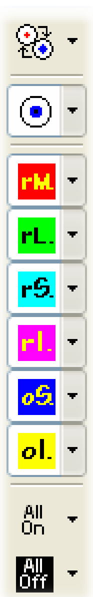
By default the boundaries of the coordinate axes in each of the two Hess-diagrams are chosen in a way that all visible points within the diagram can be ideally displayed (in the default gaze pattern e.g. from -40° to +40° horizontal and vertical). Due to the possibly different number or different locations of points in both fixations, it can happen, that both diagrams use different boundaries for the coordinate axes. With this function you can enforce, that both Hess-diagrams for left eye fixing and right eye fixing use the same boundaries for the coordinate axes. You can also access this function via the main menu under "Options->Autosize Hess-Diagrams".

SMI 3D VOG Mode 

With this button you can activate a mode to use SEE++ for real-time visualization of the currently measured data of a 3D VOG (Video Oculography) system of the company SMI. Without such a system the activation of this mode is not meaningful. You can also access this function via the main menu under "Options->Visualize SMI 3D VOG Data".

Do not forget to deactivate the 3D VOG Mode again, if you do not need it any more, because as long as it is activated you cannot change the eye positions in the 3D-view (the eye positions are determined through the measured data of the 3D VOG system). Furthermore, the innervations of the muscles cannot be relocated interactively any more to avoid viewing problems.

4.7.3 3D-View Options



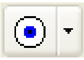
The 3D-view options toolbar offers numerous possibilities to configure the 3D-view. The bar is divided in functions for the fixing/following eye, globe and muscle options. The particular arrows besides the symbols open the related menu to make further settings.

Fixing Eye 

This symbol changes the currently fixing eye. The currently fixing eye in the 3D-view is marked through a blue cross in the cornea 111. This function can also be accessed via the main menu under "Options->Current Eye (3D)".
Left-click on the symbol once to toggle the fixing eye.

The fixing eye can also be changed via the menu, which can be displayed by clicking on the arrow besides the symbol.

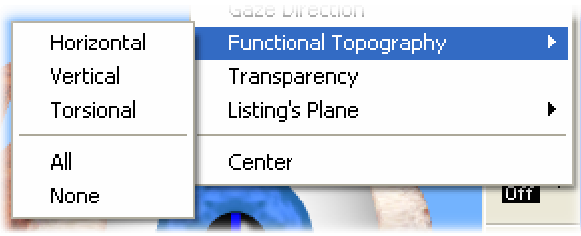
Furthermore, this function can be accessed via the tab key.

Globe Options 

With a click on this symbol the globe of the currently fixing eye (blue cross) 111 can be shown or hidden. You can also access this function via the main menu under "Options->Globes". By clicking on the arrow besides the symbol, the globe menu is displayed. All options of the globe menu always refer to the currently fixing eye (blue cross).

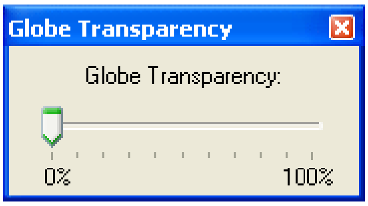
Within this menu you can find all globe specific settings for the visualization in the 3D-model.

- **Coordinate Axes (Head-Fixed)** - draws in the axes of the head-fixed coordinate system 17 in the view of the 3D-model.
- **Coordinate Axes (Eye-Fixed)** - draws in the axes of the eye-fixed coordinate system in the view of the 3D-model.
- **Description of Coordinate Axes** - displays a description of the head-fixed coordinate system axes.
- **Wireframe** - displays the globe represented through a wireframe.
- **Points of Reference** - shows the points of reference 137 on the globe for a better orientation during a surgery 133.
- **Poles** - shows the poles based on the head-fixed coordinate system. These are those points, where the coordinate axes pierce the globe.
- **Cornea Marker** - shows the cornea cross (blue or red), which gives information about the currently fixing eye and accordingly the following eye.
- **Gaze Direction** - shows the gaze direction for the current eye. This is the vector pointing from the center of the globe through the center of the cornea.

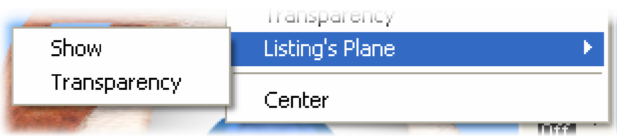


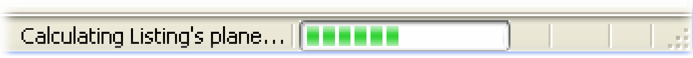
- **Functional Topography** - allows to change the settings for the functional topography 33. Within this submenu you can show and hide the different rotational components (horizontal, vertical and torsional).

Through the selection of "All", all rotational components are shown. When selecting "None", all rotational components are hidden and the functional topography for this eye is deactivated. The functional topography projects the selected rotational components in the form of different colors onto the globe. The mapping of the colors is the same as in the muscle force distribution 115 (horizontal components are blue, vertical components are red and torsional components are green). If more components are shown at the same time, the colors are combined respectively. The visualization of the functional topography depends on the currently visible muscles. Further information concerning the mathematical background can be found in the chapter geometrical models 33.



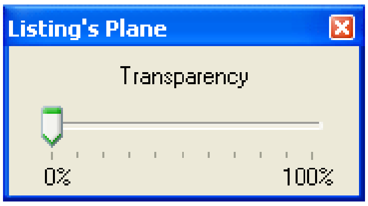
- **Transparency** - displays the dialog for the configuration of the globe transparency. You can also access this dialog via the main menu under "Views->Globe Transparency".





- **Listing's Plane** - shows Listing's plane 27 in the 3D-view and allows to set its transparency.

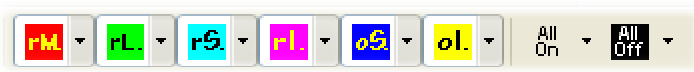
If you choose "Show", Listing's plane is calculated based on the current simulation for the appropriate eye and is displayed in the 3D-view. The calculation of Listing's plane can possibly take some time. The current calculation progress is displayed in the status bar.



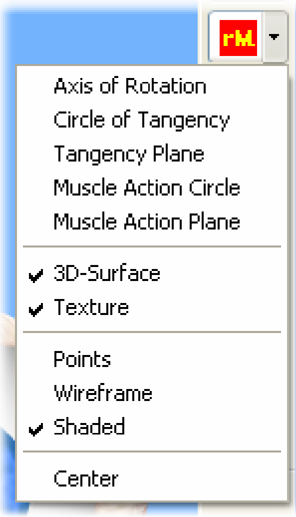
Via the menu item "Transparency" you can display the dialog for the configuration of the transparency of Listing's plane.

- **Center** - displaces the 3D-view in a way that the center of rotation is equivalent to the center of the globe of the currently fixing eye. This displacement stays active as long as the centering is switched off or the other eye is centered.

Muscle Options



The display options for the eye muscles are numerous. For each muscle there exists a symbol labeled with a character shortcut (rM = medial rectus muscle, rL = lateral rectus muscle, etc.). By left-clicking on a muscle symbol, the appropriate muscle is shown or hidden in the 3D-view. Additionally, the symbols "All On" and "All off" provide the possibility to show or hide all muscles with a single click. These functions can also be accessed via the main menu under "Options->Muscles". At the same time the currently visible muscles influence the muscle force vector diagram 115 and the muscle force distribution diagram 115 as well as the functional topography 33, because for these views the accumulated values of all muscles, which are currently visible in the 3D-view, are used. Therefore, if you want to display for example the muscle force distribution of the medial rectus muscle, you have to switch off all other muscles.



For each muscle symbol there exists an additional menu with options, which can be opened with a left-click on the arrow besides the symbol. The options contained in the menu have the following effects:

- **Axis of Rotation** - draws in the axis of rotation in the particular color of the muscle around which the globe in the current eye position would be rotated. Obviously, the axis of rotation is changed, if the globe is set to another eye position. This calculation is based on the currently used model 120.
- **Circle of Tangency** - draws in the circle of tangency in the particular color of the muscle (shadow circle of the point of tangency) with a dashed line.
- **Tangency Plane** - draws in the tangency plane in the particular color of the muscle.
- **Muscle Action Circle** - draws in the action circle of the muscle in the current gaze direction (see also Ant./Post. Transposition 135).
- **Muscle Action Plane** - draws in the action plane of the muscle in the current gaze direction.

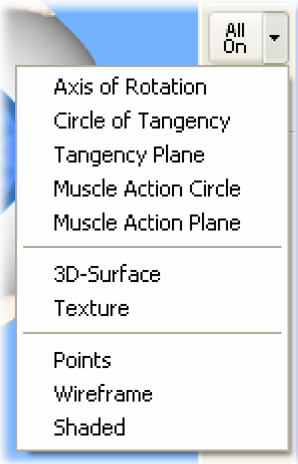
By default all muscles in the 3D-view are plotted as 3D-surfaces. These 3D-surfaces are additionally covered with a texture (sticked on image) to achieve a realistic visualization. The following options of the muscle menu refer to the settings of the 3D-surface of a muscle.

- **3D-Surface** - shows or hides the 3D-surface. If the 3D-surface is hidden, a muscle is plotted as a line in the particular muscle color. The line thickness can be set via the "General Options" 141 menu.
- **Texture** - shows or hides the over-subscription of the 3D-surface of a muscle with a muscle image.

If the visualization of the 3D-surface of a muscle is shown, you can additionally choose between 3 different options:

- **Points** - the muscle surface is displayed as points
- **Wireframe** - the muscle surface is displayed as a wireframe model
- **Shaded** - the muscle surface is displayed as a solid model (this is the default setting)

The menu item "Center" rotates the whole 3D-view (camera) in a way that the selected muscle is visible in the best possible way.



When clicking on the arrow besides the symbol "All On", the appropriate context menu is opened. Here all functions are available, which are also listed for each muscle, except the option "Center" (see above). If you use this menu, all functions refer to all muscles and accordingly activate the chosen option. The menu besides the symbol "All Off" is nearly the same, with the difference, that here the selected option is deactivated.

4.7.4 Views

The views toolbar is used to administrate different views. A view is the sum of all settings, which can be made for the diagrams and the 3D-model in SEE++. Therefore, a view consists of a large part of the settings, that can be made in the 3D-view options toolbar 124, in the general functions toolbar 121 as well as in the different dialogs for the diagram options 144. The settings of the currently displayed view in the program are automatically saved when exiting SEE++ and are restored when starting the application the next time.

The list in the views toolbar shows a listing of all available (previously saved) views. To load one of this views, it only has to be selected in the list. The selected view automatically becomes the active view.

 Use this button to create a new view. After clicking on this button a dialog is displayed, where you have to enter the name of the view. The name has to be at least 1 character long and there must not exist a view with the same name. After confirming the dialog with "OK", a new view is added to the list and is automatically set as the active view.

 With this button you can load the active view. If the current view and the currently active view are the same, the loading of the active view has no effect.

 With this button you can overwrite the active view with the current view. That means that you are saving the currently set view into the currently active view. The previously saved settings of the active view are lost during this process.

 For renaming the currently active view use this button. After clicking on this button a dialog appears, where you can change the name of the view. The name has to be at least 1 character long and there must not exist a view with the same name.

 If you want to delete the active view click on this button.

If you have loaded a view (e.g. via the list in the views toolbar or via a scenario with an assigned view), you can use this button to undo the loading of the last view and restore the previously set view. Up to 20 loadings can be undone.

You can use this button to restore a previously undone loading. Up to 20 undone loadings can be restored.

With this button you can reset all settings of the current view to the default settings. The currently active view is thereby set inactive. The resetting of the current view is treated like a loading and can therefore also be undone (see above).

4.8 Methods for Motility Diagnosis

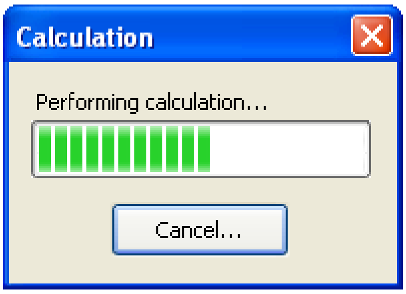
In SEE++ there exist two possibilities for the interactive motility diagnosis:

1. Interpolation for Real-Time Assessment 130
2. Cover Test 131

You can access these two functions via the "General Functions" toolbar 121. As long as one of these two functions is activated, you cannot make changes in SEE++ which would lead to a recalculation of the simulation results (e.g. a change of the medical data 85 or the loading of another scenario 98). The motor fusional ability 90 forms an exception as it can still be modified when one of those functions is activated, since it is used for the simulation of the cover test.

4.8.1 Interpolation for Real-Time Assessment

The interpolation for real-time assessment can be accessed via the "General Functions" toolbar 121. After clicking on the appropriate button, a dialog is opened, which displays the current calculation progress. With a click on "Cancel" you can stop the calculation at any time. In that case the interpolation for real-time assessment is not activated.

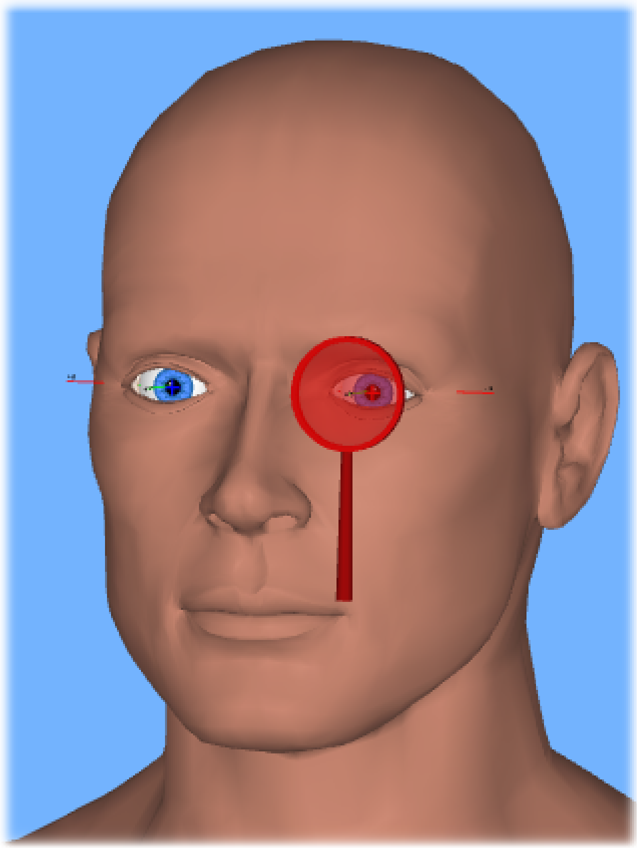


Normally SEE++ only calculates the position of the following eye, if the option "Following Eye" 122 is activated. When changing the position of the fixing eye, the position of the following eye is not updated until the mouse button is released (when changing the fixation position in the 3D-view 111 or in one of the diagrams 144), even if this option is activated. Therefore, an interactive motility diagnosis is hard to achieve. If the interpolation for real-time assessment is activated, the eye positions, based on a completely calculated Hess-diagram for the right eye fixing and the left eye fixing within the area determined through the fixation positions, are interpolated. This allows an immediate viewing of the position of the following eye as the movement of the following eye can be monitored in real-time when interactively changing the fixation position in the 3D-view or in a diagram. This behaviour is conform to the procedure used in clinics for the motility diagnosis, where the clinician let the patient fixate a specific gaze position with one eye and watches the behaviour of the other (following) eye.
As long as the interpolation is activated, only positions within the area determined through the points of the particular gaze pattern can be fixed. If you want to fixate points outside this area, you have to enlarge the appropriate gaze pattern 91 (you have to switch off the interpolation for real-time assessment before you can edit the gaze pattern!). In order to activate the interpolation, at least 3 fixable gaze positions in both fixations must exist. The more points the gaze pattern of the particular fixation contains, the better and more precise is the interpolation.
Due to the fact, that for the interpolation a completely calculated Hess-diagram is required, you cannot make changes in SEE++, which would lead to a recalculation of the simulation results as

long as the interpolation for real-time assessment is activated (e.g. a change of the medical data 85 or the loading of another scenario 98).

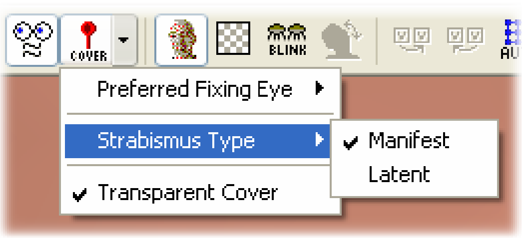
4.8.2 Cover Test

The simulation of the cover test is based on the "Interpolation for Real-Time Assessment" 130, so before using the cover test you have to activate the interpolation for real-time assessment. If you access the cover test via the "General Functions" toolbar 121, the interpolation for the real-time assessment is automatically activated. When deactivating the cover test, the interpolation is also switched off again. All properties described for the interpolation for real-time assessment can be applied to the cover test as well. The medical background of the cover test can be found in the chapter "Cover Test" 50.



After activating the cover test and after the calculation of the interpolation is finished, a three-dimensional red cover is displayed in the 3D-view. Now you can left-click on this cover and when you move the mouse while keeping the mouse button pressed, you can cover one of the two eyes. If a pathological situation exists, a movement of the eye to pick up fixation can be observed after one eye was covered/uncovered depending on the current settings of the cover test. To modify the settings of the cover test, you can use the menu, which can be accessed with a left-click on the arrow next to the symbol for the activation of the cover test.

In this menu you can configure the following settings:



- **Preferred Fixing Eye** - specifies the eye, which the "virtual patient" prefers to use for the fixation (after the cover from one eye was removed or if no eye is covered). If the left or the right eye is chosen, the patient always fixates with the selected eye until it is covered.

  When using the setting "Both Eyes" the "virtual patient" always fixates with the eye, which was uncovered at last.
- **Strabismus Type** - specifies the strabismus type. If "Manifest" is selected, then the full squint angle is visible in the 3D-view independently of the position of the cover. If the strabismus type

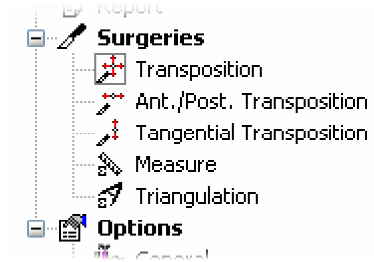
"Latent" is chosen, a part of or the whole squint angle is compensated in a certain gaze position depending on the current motor fusional ability 90. If you now change the motor fusional ability, the change is shown in the 3D-view immediately.

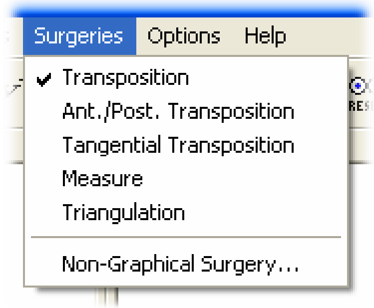
- **Transparent Cover** - by default the cover is drawn in a semi-transparent way, so that the covered eye and its movement to pick up fixation during the covering are visible. With this function you can switch off the transparency of the cover.

If you select a preferred fixing eye or if one of the two eyes is covered, you cannot switch the fixation as long as the cover test is active or one of the eyes is covered!

4.9 Surgeries

SEE++ interactively simulates the most popular surgery techniques. If you want to simulate a surgery with the system, a surgery step always consists of a combination of different standard elements.





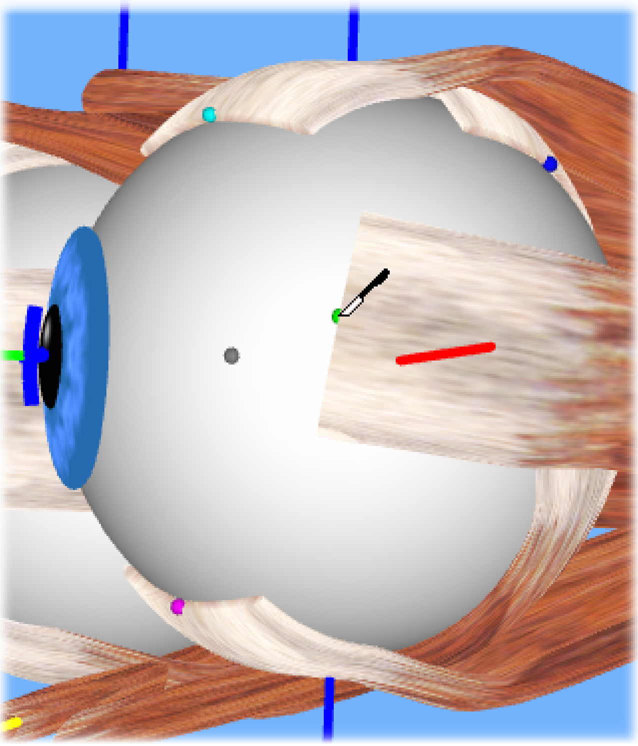
If you for example want to carry out a resection and afterwards a transposition of a muscle, you would first simulate the resection in the form of a change of the parameters "Tendon Length" 44 and respectively "Muscle Length (L0)" 44 in the force model and afterwards carry out the surgery "Transpostition" 133 interactively in the 3D-view 111. However, a resection as well as a plication can also be carried out via the "Non-Graphical Surgery" 134 dialog. In this case, the system automatically applies the resection or the plication on the tendon length and muscle length (L0) parameter in the background.

If it is necessary to define the new location of an insertion point via marking off from the points of reference, you can use the methods "Measure" 136 and "Triangulation" 137. Of course a non-graphical 134 transposition of a muscle insertion is also possible.

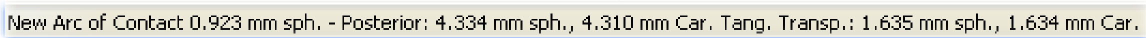
For performing a virtual surgery navigate in the Treeview 79 to "Surgeries" and select the desired procedure with a left-click. You can find the same functions in the main menu under "Surgeries".

4.9.1 Transposition

The transposition of an insertion can be performed in an interactive or in a non-graphical 134 way. If you want to transpose an insertion with the mouse, select the surgery technique "Transposition" 133 and move the cursor directly over the insertion point in the 3D-view 111. As soon as the cursor is located over the insertion point, the cursor changes its shape into a scalpel.

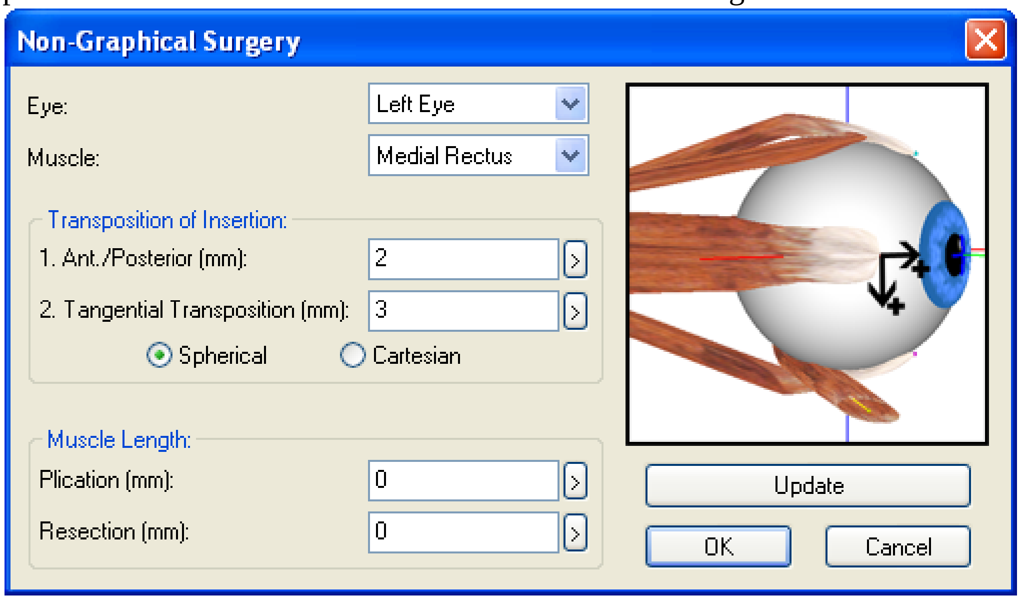


Now click with the left mouse button directly on the insertion point and pull it to the desired position on the globe, while keeping the mouse button pressed. The gray point marks the location of the insertion before the transposition was started. By releasing the left mouse button, the transposition is finished. By pushing the "ESC" key 113 the transposition can be canceled as long as the left mouse button is still pressed. Furthermore, you can push the "CTRL" key or move the mouse wheel, while holding the left mouse button down and pulling the mouse, in order to zoom the 3D-view. During the transposition, the new arc of contact as well as the anterior/posterior and tangential transposition distances in spherical and Cartesian distances are displayed in the status bar 79.



4.9.1.1 Non-Graphical

The transposition of an insertion can also be carried out in a non-graphical way. To do so, open the dialog for the non-graphical transposition via the main menu 79 under "Surgeries->Non-Graphical Surgery..." or simply right-click on one of the surgery techniques 133 in the Treeview. A plication or a resection can also be carried out with this dialog.



First select the particular eye from the drop down box on which you want to perform the surgery (the currently fixing eye is selected automatically when opening the dialog). Afterwards, select a muscle from the second drop down box. The transposition of the insertion is divided into two directions.

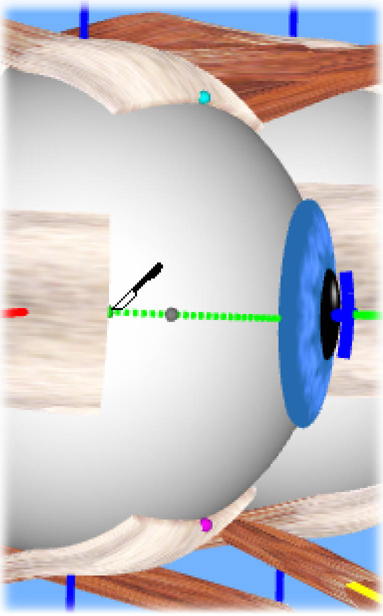
1. Anterior/Posterior Transposition 135
   Here you can enter the distance in mm that you want to transpose the insertion point along the muscles direction of action (on the muscle action circle in primary position). A positive distance is a transposition in posterior direction (towards the pupil) according to the image in the dialog. A negative distance is equivalent to a transposition in anterior direction (towards the anatomical origin of the muscle).
2. Tangential Transposition 136
   In the second step the transposition along the circle of tangency is entered in mm. A positive distance describes a displacement towards the direction of the intorsion, a negative distance transposes the insertion towards the direction of the extorsion.

When the dialog is opened again, the transposition distances are still displayed. They always refer to the position of the current insertion point (which is stored in the medical data) compared to the position of the insertion point stored in the active scenario 98. Therefore, you can access this dialog repeatedly and change the values until the modifications are finally saved in a scenario. Furthermore, you can choose how the calculation of the distance shall be done. There exists the possibility of a spherical or Cartesian calculation of the distances.
Besides the transposition of an insertion, you can also perform a plication or resection surgery in this dialog. To do so enter the desired value into the appropriate field. The values for resection and plication are also displayed again after reopening the dialog. They always refer to the current tendon length and the muscle length (L0) stored in the medical data compared to the values stored in the active scenario 98. Therefore, you can access this dialog repeatedly and change the values until the modifications are finally saved in a scenario.
Push the "Update" button to store the entered values into the simulation model. SEE++ updates the 3D-view immediately according to the new values and recalculates the simulation result in the background. If you have clicked on the "Update" button, the changes are stored even if you exit the dialog via the "Cancel" button.
When you are finished, confirm the dialog by pressing the "OK" button or push the "Cancel" button, if you do not want to make changes.

If you change the selected eye or the selected muscle after entering values for the anterior/posterior transposition, the tangential transposition, plication or resection, the entered values are lost, if you did not push the "Update" button before.

4.9.2 Anterior/Posterior Transposition

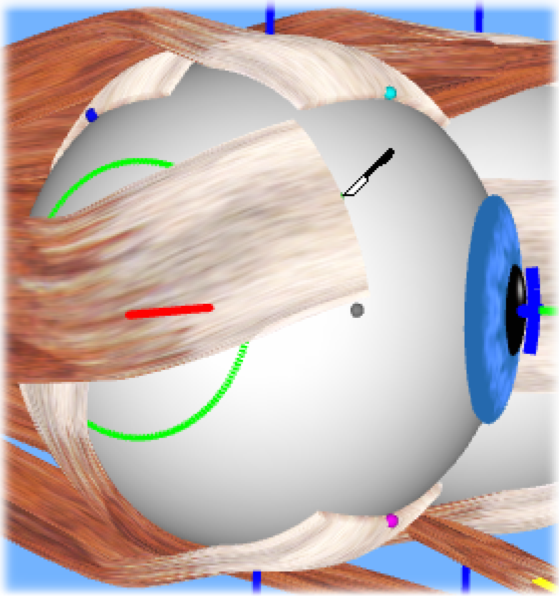
The surgery technique anterior/posterior transposition relocates an insertion point along its muscle action circle. If the eye is not in primary position, the muscle is relocated along the rotated primary position muscle action circle (this is equivalent to the muscle action circle in primary position rotated into the current gaze position).



To do so, select in the Treeview 79 under "Surgeries" the entry "Ant./Post. Transposition" or in the main menu 79 the entry "Surgeries->Ant./Post. Transposition". Afterwards, move the curser directly over the insertion point that you want to transpose so that the cursor changes its shape into a scalpel. Now push the left mouse button and pull the insertion point to the desired position, while still pressing the left mouse button. Thereby, the transposition is restricted to the muscle action circle. Therefore, in this surgery technique you cannot move the insertion point upwards or downwards.
In this example the lateral rectus muscle of the right eye is transposed on its drawn in muscle action circle 126 (in primary position). The gray point marks the location of the insertion before the transposition. The handling is the same as in the "normal" surgery technique transposition 133.

4.9.3 Tangential Transposition

The tangential transposition works similar to the transposition 133 or the anterior/posterior transposition. To do so, select in the Treeview 79 under "Surgeries" the entry "Tangential Transposition" or in the main menu 79 under "Surgeries" the entry "Tangential Transposition".



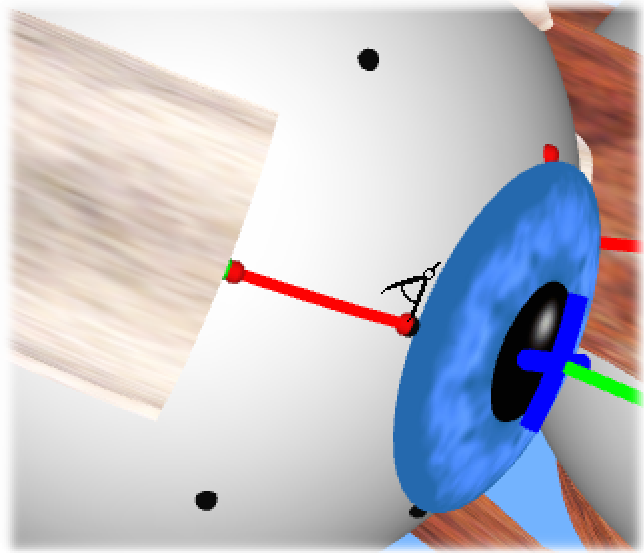
In this example the lateral rectus muscle of the right eye is tangentially transposed. Thereby, the transposition is reduced to the circle parallel to the drawn in circle of tangency. The gray point marks the location of the insertion before the transposition. The handling is the same as in the "normal" transposition 133 surgery technique.

4.9.4 Measure

During surgeries new points are marked off from so-called points of reference with a pair of compasses for the orientation on the globe. Normally the points of reference are located around the pupil. Further points are created through the marking off of spherical distances and offer the possibility to carry out a real surgery in a better way. The SEE++ system offers this possibility by supporting two measurement procedures. On the one hand it is possible to measure any spherical distance on the globe with a virtual pair of compasses. On the other hand you can use the

"Triangulation" 137 function to simulate the marking off of two distances for drawing in new points of reference.

To access the measuring function select the entry "Surgeries->Measure" via the Treeview 79 or via the main menu. Afterwards, move the curser over one of the two globes. If you now push the left mouse button, the curser changes its shape and shows the symbol of a pair of compasses.

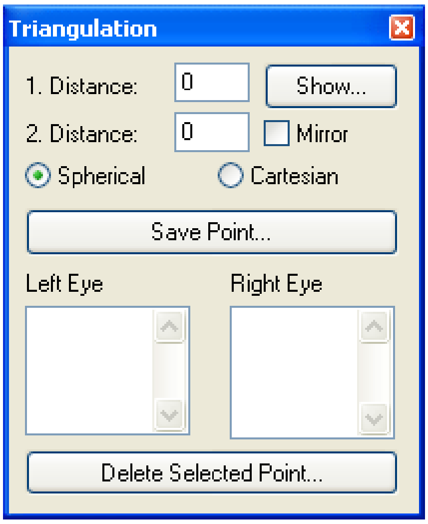


If you pull the mouse over the globe while still pressing the left mouse button, a spherical line is drawn from the previously clicked point to the current position. At the same time the appropriate distances (spherical and Cartesian) are displayed in the status bar 79. The measured line can be modified until the left mouse button is released. Afterwards, the measured line is fixed and remains visible until a new measurement is carried out.

Furthermore, the distances in the status bar are displayed as long as the cursor is located inside the 3D-view over the globe used for measurement. By pushing the "ESC" button during the measurement it can be aborted.

As long as "Measure" is selected as the active surgery type, you cannot transpose muscle insertions (neither interactive 133 nor non-graphical 134)!

4.9.4.1 Triangulation

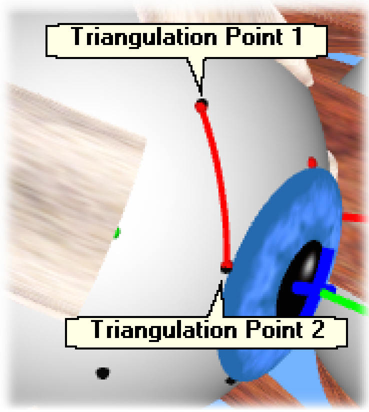


The triangulation is based on the measurement 136 function, whereas here the marking off with a pair of compasses is supported. To access this function select the entry "Surgeries->Triangulation" from the Treeview or from the main menu. A dialog is displayed that assists you with the triangulation. This dialog offers the possibility to store new points in a list of points for each eye, which were marked off with the aid of the triangulation function. These points are saved with the patient data and can always be displayed via the "Points of Reference" 124 function. Consequently, if you want to show the previously marked off (and stored) points again, you have to enable the visualization of the points of reference for the specific eye.

A point can be marked off in two different ways:

1. Textual input of the distances
2. Interactive marking off with the mouse

In both variants, you first have to define the measured section or the two points, from where you want to mark off. This section is defined in the same way as in the "Measure"[136] function. If you have measured a distance with the "Measure" function before and the measured section is still displayed, you can proceed with the triangulation by determining the two distances you want to mark off.



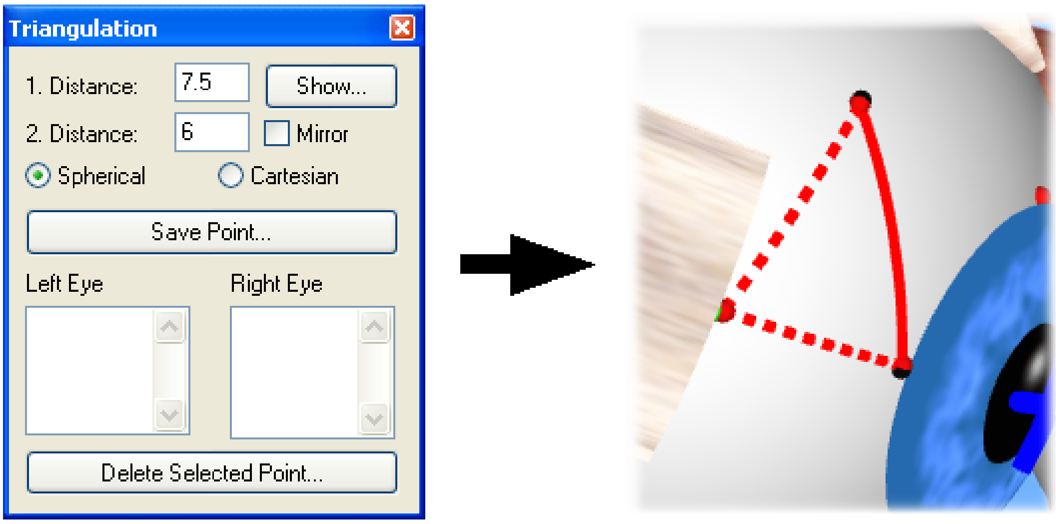
Otherwise, you have to move the cursor over one of the two globes. Then you perform a left-click onto the globe and while keeping the left mouse button pressed you draw in a section. If the mouse button is released at the end of the measured section, two points are drawn in. They represent the initial points for the triangulation. After the measured section was drawn in, you can continue immediately with the triangulation.

As long as "Triangulation" is selected as the active surgery type you cannot transpose muscle insertions (neither interactive[133] nor non-graphical[134])!

Textual Input of the Distances

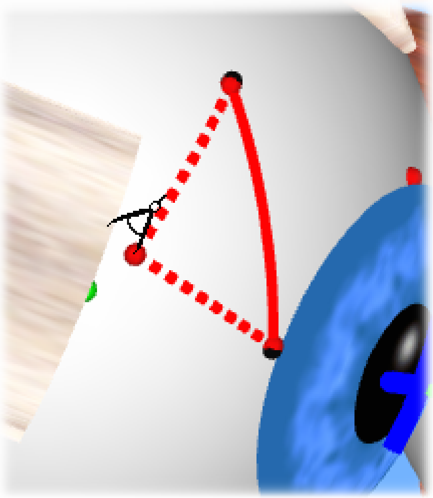
If you want to input the distances textually, you have to fill in the fields "1. Distance" and "2. Distance" in the triangulation dialog and afterwards click on "Show...". Now the distances are marked off and the new point is drawn in connected with dashed lines. You can repeat this procedure as long as you want. With "Spherical" and "Cartesian" you can determine the type of the distance calculation for your entered values. Due to the fact that you can mark off two possible points at a time, you can use the option "Mirror" to draw in the respective opposite point.

Another possibility is to input only one distance and define the other one interactively with the mouse. Therefore, enter either the distance to the first or to the second point, set the respective other distance to 0 and afterwards click on "Show...". Now you can move the resulting point along the circle where the entered distance is always fulfilled. This way you can interactively define the second distance. To move the drawn in point simply left-click on it and change its position by moving the mouse with the left mouse button pressed.



If you have entered both distances textually, you cannot move the marked off point with the mouse!

Interactive Marking off with the Mouse



To interactively mark off with the mouse, you have to left-click on the target point, which you want to mark off, after defining a section. You can keep the left mouse button pressed and pull the mouse anywhere you want. You can also left-click on the marked off point later and change its position while moving the mouse with the left mouse button pressed.

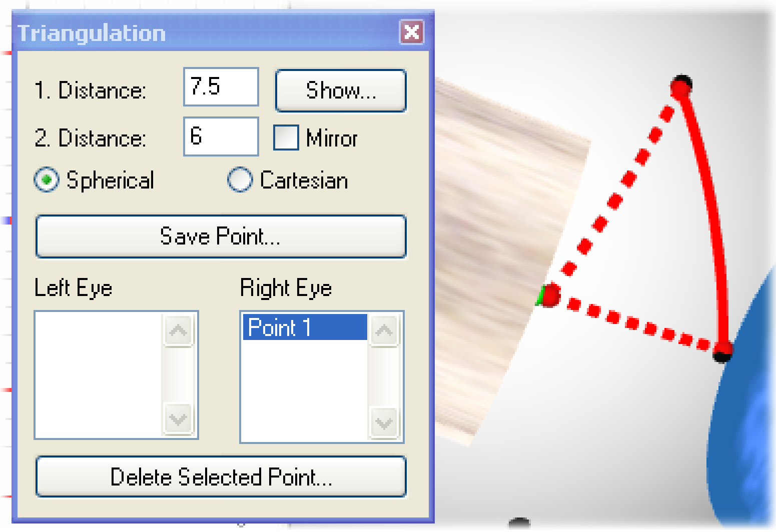
Status Bar

Distance to 1. Point: 5.934 mm sph., 5.873 mm Car. / Distance to 2. Point: 5.370 mm sph., 5.325 mm Car.

In both variants the two marked off distances are displayed in the status bar 79 as soon as the cursor is located over the globe that was used for the marking off.

Saving of Points

After a point was marked off, you can save it together with the patient data. Therefore, simply click on "Save Point...". The point is inserted into the list of the corresponding eye.



By clicking on a saved point in one of the lists, the point is displayed on the globe again. Once a marked off point is saved, it is taken into account as an additional reference point and shown together with the other reference points if the option "Points of Reference" 124 is activated.

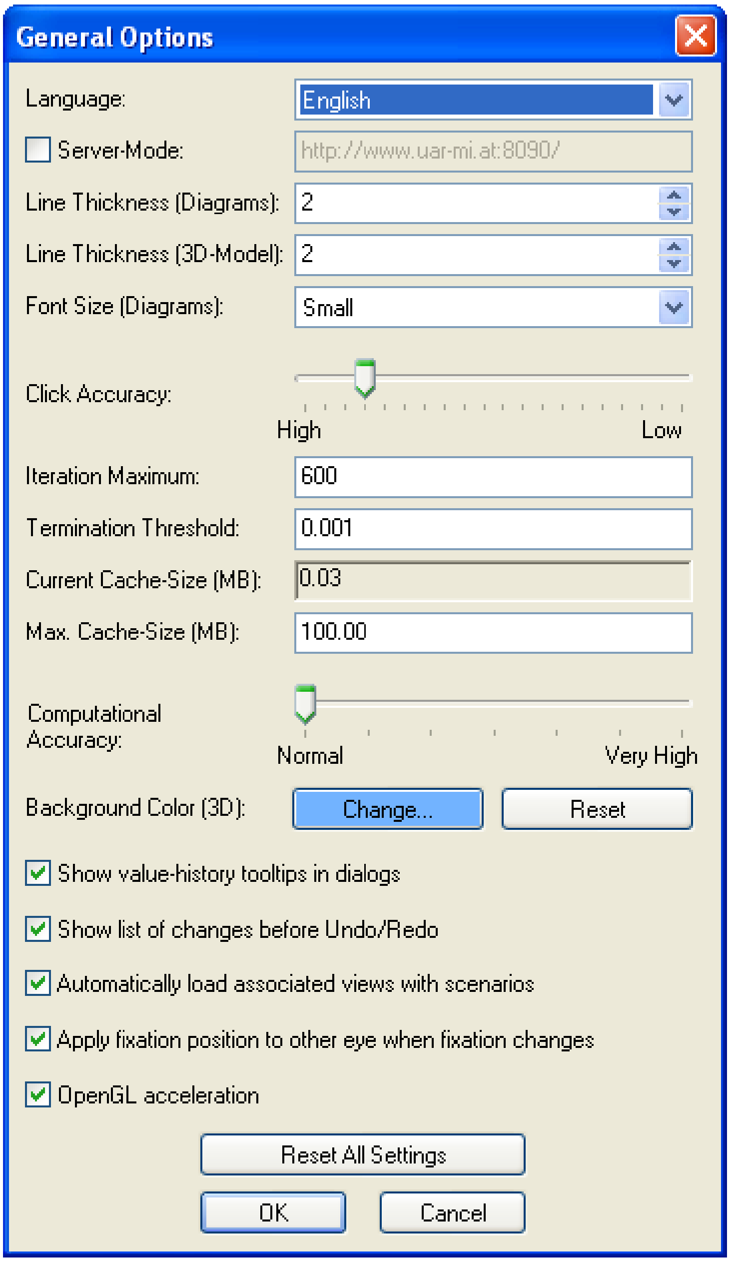
If you want to delete a saved point, click on the point in the list and afterwards on "Delete Selected Point...".

If you keep the left mouse button pressed during the triangulation and draw in a section or a point to mark off, you can cancel the procedure anytime by hitting the "ESC" key.

4.10 Options

SEE++ provides general options, which allow specific default settings to make it easier to work with the system. Each time SEE++ is quit, all settings described in the following sections are saved by the program into a configuration file. The settings of all options are stored independently of the patient data 80. If it happens that the program does not react in an appropriate way anymore, you can reset all options to the initial state via the "Reset All Settings" button in the "General Options" 141 dialog.

4.10.1 General



The general options of SEE++ can be set in a dialog, which can be accessed via the Treeview 79 under "Options->General" or via the main menu 79 under "Options->General Options".

Language
You can set the current language of the program via the "Language" drop down box. Currently, German and English are supported. Select the appropriate language and confirm the dialog by clicking on "OK". To make this change effective, you have to restart SEE++ afterwards.

OpenGL Acceleration
If you experience problems with the 3D-view or if the view is too slow, you can achieve an improvement of the view by selecting the "OpenGL Acceleration" checkbox. To make this change effective, you also have to restart SEE++ afterwards.

Server-Mode
If you activate this option, SEE++ tries to carry out all calculations via the SEE++ Calculation Server (available as a separate product on www.see-kid.at). You can enter the server address

into the input field. The server-mode is primarily designed for the usage in larger networks, where the calculations can be sourced out to a powerful server. Therefore, the hardware requirements of the clients can be lowered.

Reset All Settings
SEE++ automatically saves all settings when you quit the program and restores them at startup. If it happens that the program does not react in an appropriate way anymore or if you want to reset all settings to their default values, you can restore the initial state of all options with a click on this button. After clicking on this button, SEE++ has to be restarted to successfully finish this process.

Line Thickness (Diagrams)
This option defines the thickness of all lines that are drawn in in the different diagrams 144.

Line Thickness (3D-Model)
This option defines the thickness of all lines that are drawn in in the 3D-view 111.

Font Size (Diagrams)
With this option you can change the font size of the text drawn in the different diagrams. You can choose between small, medium and large fonts.

Click Accuracy
Everywhere in SEE++, where you can click on points, the click accuracy is considered. For example, in the 3D-view the insertion points or in the diagrams the cross representing the current gaze position are affected. Choose a value in the "Low" range to achieve a large tolerance for the positioning of the cursor over clickable points (e.g. cursor changes its shape already in larger distance to an insertion point). If you confirm the dialog with "OK", the changes immediately take effect.

Iteration Maximum
The iteration maximum is a setting that is used for the non-linear optimization. Increase this value, if the simulation results calculated by SEE++ obviously correspond to values resulting from a too early termination of the search for an eye position. Decrease this value, if SEE++ needs a long time for the calculation of the simulation result. The iteration maximum should lie within the range from 100 to 2000!

Only change this value if you are absolutely sure. An inappropriate change of this value can invalidate all simulation results.

Termination Threshold
With this option you can set the accuracy of SEE++ for the calculation of simulation results. By default SEE++ considers three places after the comma for calculations. Changes of this value should lie within the range from 1e-03 to 1e-15.

Only change this value if you are absolutely sure. An inappropriate change of this value can invalidate all simulation results.

Current Cache-Size (MB)
Shows the current size of the calculation cache in megabytes. This value cannot be changed.

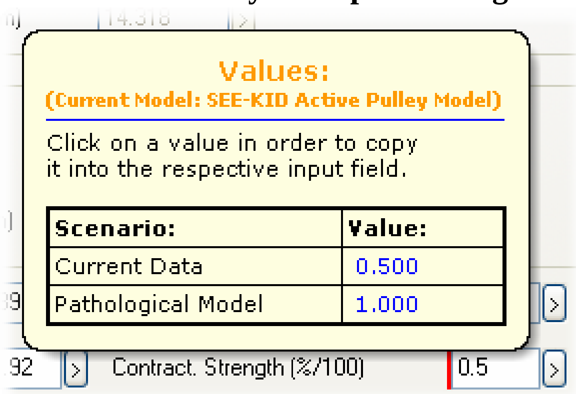
Maximum Cache-Size (MB)
SEE++ internally uses a cache to avoid the recalculation of already calculated simulation results. With this option you can define the maximum size of this cache in megabytes. If you set the maximum cache to 0, the cache is deactivated (not recommended!). Only increase the maximum cache-size, if your computer has a lot of main memory (RAM >2GB). Otherwise increasing the cache-size can possibly slow down SEE++.

Computational Accuracy
The computational accuracy is a setting that is used for the non-linear optimization. This value defines the number of times SEE++ changes the initial values during the calculation of a simulation result to avoid local minima. Change this setting, if you think that SEE++ displays local minima as simulation results. Normally you do not have to change the default value.

Only change this value if you are absolutely sure. An inappropriate change of this value can invalidate all simulation results.

Background Color (3D)
Here you can change the background color of the 3D-view. By default the color is set to the values "Red: 114, Green: 179, Blue: 255". Click on "Change..." to choose a new background color. With a click on "Reset" you can restore the default color.

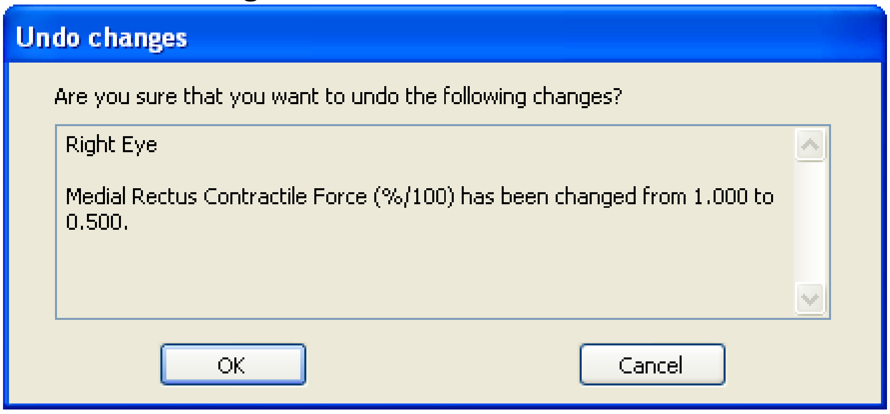
Show Value-History Tooltips in Dialogs



With this option you can configure if tooltips with a list of the previous values (based on the different scenarios 98) of a specific parameter are shown in any of the medical data dialogs (globe data 85, muscle data 86, distribution of innervations 89, motor fusional ability 90). Within the tooltip window you can click on one of the previous values to copy it into the appropriate input field. Furthermore, the current model is displayed in the tooltips.

If a specific value has changed in comparison to the currently selected scenario or to the parent scenario of the current scenario, the respective input field is additionally marked with a red line on the left side.

Show List of Changes Before Undo/Redo



If you undo or redo a change via the "General Functions" toolbar or via the main menu under "Data", by default a dialog with a short overview of the changes is displayed. With this option you can switch off this dialog. The undoing and redoing of a change is then carried out directly without displaying the dialog.

Automatically Load Associated Views with Scenarios

By default when loading a scenario, the assigned view is also loaded automatically (the current view is overwritten in this process). Of course this only happens if a view was previously assigned [103] to the loaded scenario [98]. If you do not want that assigned views are automatically loaded with a scenario, you can disable this behaviour with this option.

Apply fixation position to other eye when fixation changes

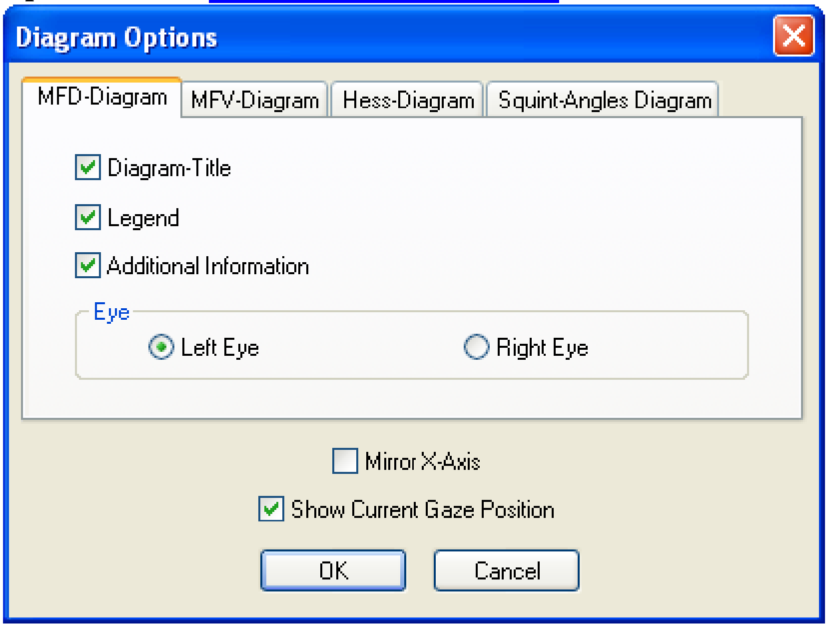
If the currently fixing eye is changed by using the "3D-View Toolbar" [124] or by pressing the tab key, the position of the new fixing eye is set to the position of the previously fixing eye. If you do not want this to happen, you can disable this behaviour with this option. During the simulation of the cover test [131] the gaze position of the new fixing eye is always set to the position of the previously fixing eye after a change of the fixation, independent of the configuration of this option.

4.10.2 Diagrams

The options for diagrams [114] refer to the visualization of the different views [109] available in SEE++. In this dialog there exists a tab sheet for each type of diagram [114] (except for the Stateviewer), which can be used to configure the different settings. To access this dialog select the entry "Options->Diagrams" via the Treeview or via the main menu.

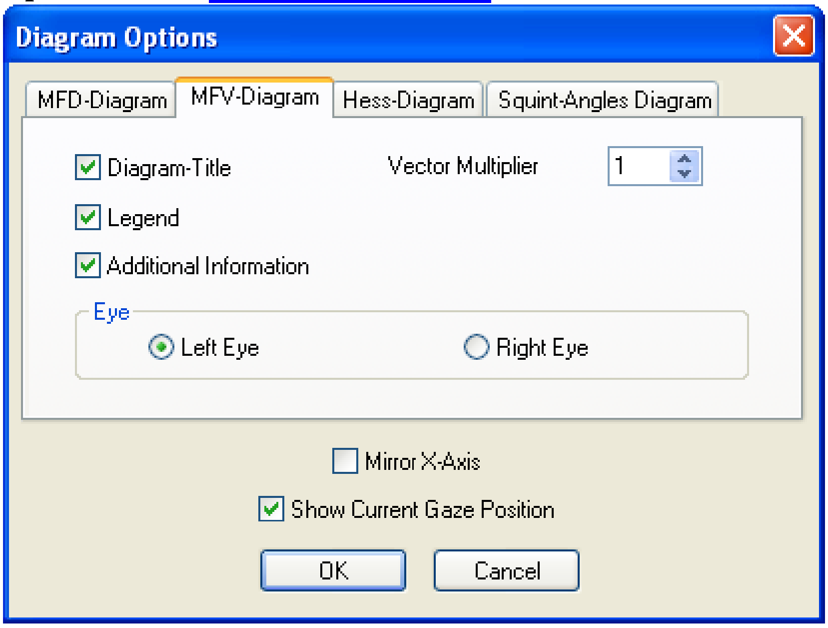
With the option "Mirror X-Axis" you can mirror the horizontal axis (x-axis) for all diagrams. Furthermore, with the option "Show Current Gaze Position" you can show or hide the current gaze position, displayed in the form of a cross or a line, in all diagrams.

Options for the Muscle Force Distribution 115



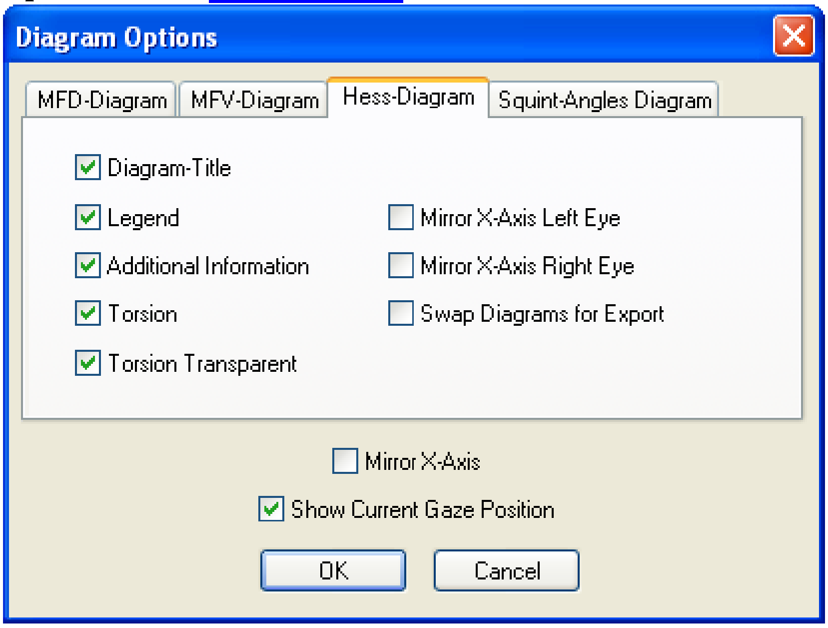
The tab sheet MFD-Diagram (Muscle Force Distribution Diagram) offers the possibility to switch between the left and the right eye ("Eye" box). Furthermore, you can show or hide the diagram-title, the legend and the additional information. The additional information refers to the specification of the used model 120, the current gaze position 16 (elevation/depression) and the currently viewed muscles 115 in the diagram.

Options for the Muscle Force Vector 115



The tab sheet MFV-Diagram (Muscle Force Vector Diagram) also offers the possibility to switch between the left and the right eye ("Eye" box) and features the same options as the muscle force distribution diagram. Additionally, the "Vector Multiplier" setting offers the possibility to lengthen the vectors drawn in the diagram 115 to achieve a better view.

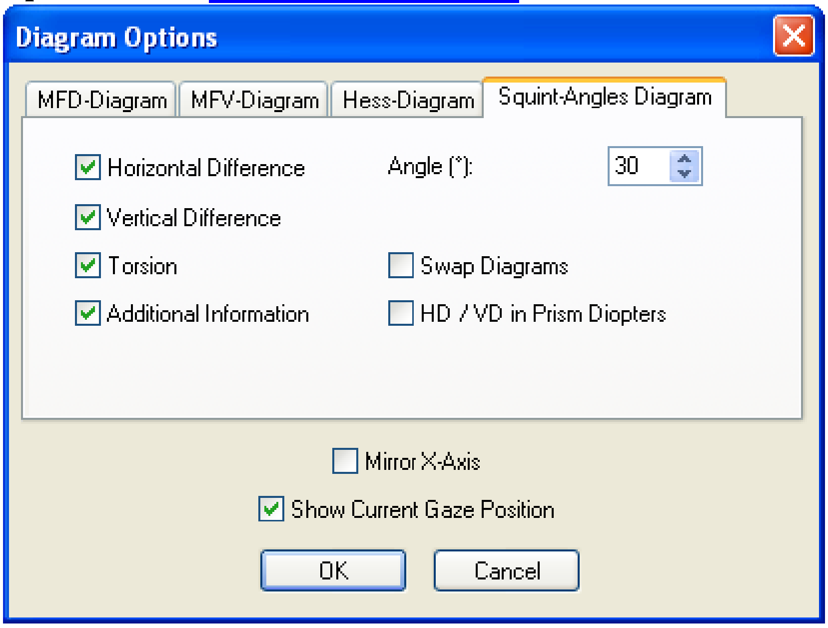
Options for the Hess-Diagram 116



You can switch the diagram-title, the legend, the additional information and the torsion 16 display in a Hess-diagram on or off. For the torsion you can additionally set if the background of a specific torsion value is drawn transparent or white. By default the background of a specific torsion value is drawn transparent. This can result in a poor readability of the torsion values, if there is a great number of points in the Hess-diagram or if the points are located very closely to each other. In this case simply disable the "Torsion Transparent" option. The torsion values are then drawn with a white background for a better readability in the diagram.

Additionally, the x-axis can be mirrored separately for right eye fixing and left eye fixing 47 (diagram is switched horizontally). To swap the default arrangement of the two Hess-diagrams (left eye (right eye fixing) on the left hand side and right eye (left eye fixing) on the right hand side) for the exporting as an image, the printing or the copying to the clipboard via the main menu under "Patient->Both Hess-Diagrams" 80, select the "Swap Diagrams for Export" option.

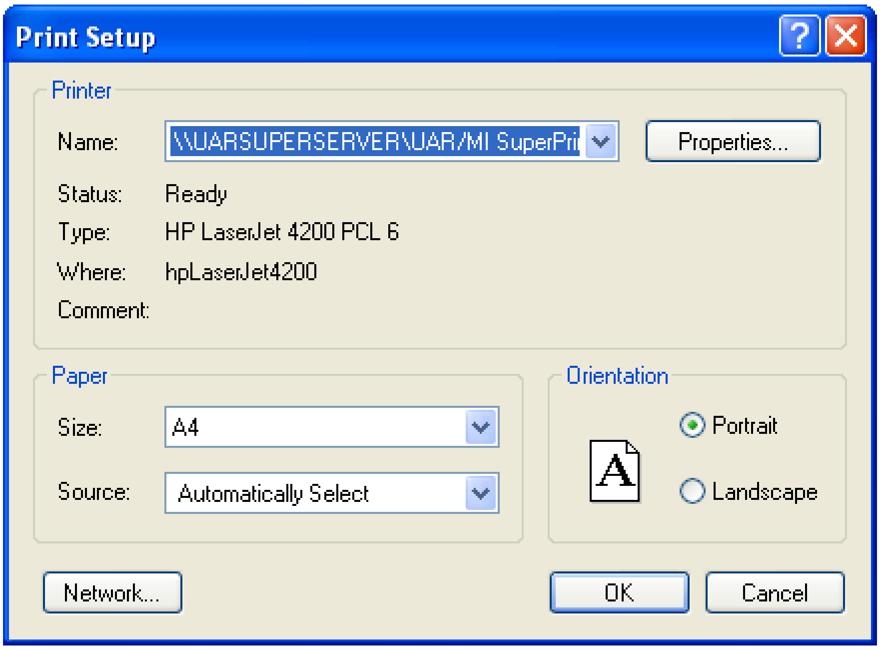
Options for the Squint-Angles Diagram 117



In the squint-angles diagram you can show or hide the horizontal difference (HD), the vertical difference (VD) and the torsion 51 as well as the additional information. Furthermore, you can modify the angle for the gaze positions and you can swap the two diagrams for right eye fixing and left eye fixing. Finally, you can configure, if the horizontal and vertical differences (HD / VD) are displayed in degrees (default setting) or in prism diopters.

4.10.3 Printer

With the "Printer" dialog you can specify the settings for the default printer used in SEE++. You can access this dialog via the Treeview 79 under "Options->Printer" or via the main menu under "Patient->Printer Setup".



You can select the desired printer with the "Name" drop down box. Additionally, you can choose the paper size and the orientation. This dialog is a standard Windows® dialog and the displayed properties depend on the printer you use with your computer.

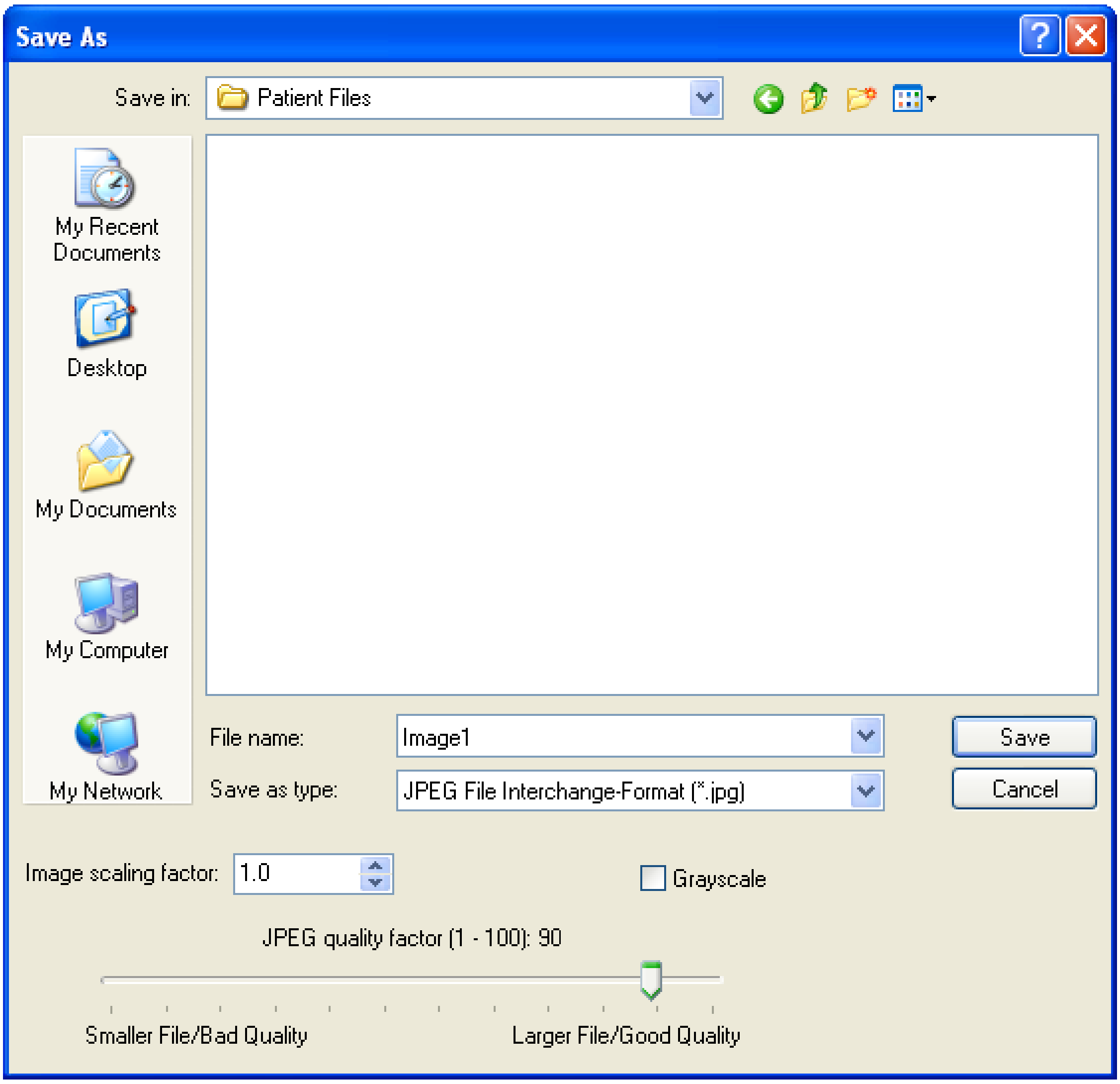
4.11 Data Export

As data export functions the saving of images, videos or the printing of diagrams and views can be summarized in SEE++. These functions can be accessed in all diagrams via the particular context menu114 which can be opened by right-clicking into a diagram window. The 3D-view111 forms an exception, because there is no context menu available. In this case, the functions for the data export can be accessed via the main menu under "Patient" or via the Treeview79 under "3D-Model".

Besides the saving of images and videos as well as the printing there exists the possibility to copy content into the clipboard. With the aid of this function, any diagram or the 3D-view can be copied to the Windows® clipboard. From there it can be inserted into any other program (that supports it).

4.11.1 Save as Image

Select "Save as Image" from the context menu of a diagram or for the 3D-view from the main menu under "Patient->3D-Model->Save as Image", to export the current view as an image.



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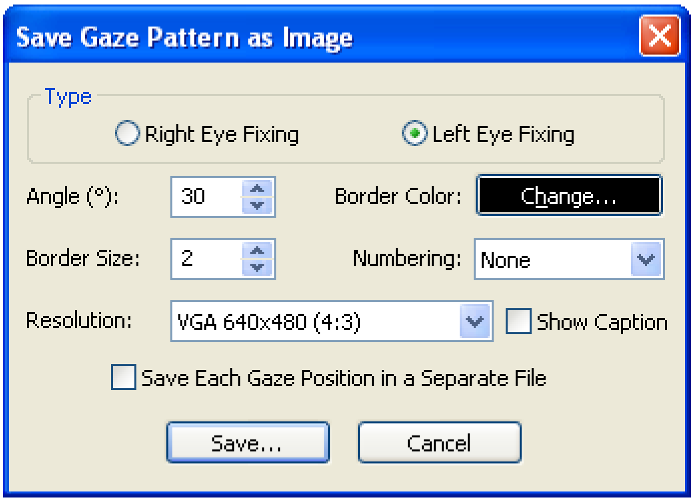
Navigate to the directory where you want to save the image file. Afterwards choose the image file format from the drop down list. SEE++ can save images in the Windows®-BMP (Bitmap) format or in the JPG (JPEG) format. If JPG is set as the target format, additionally the quality regarding the compression of the image can be selected (slider) and if the image should be converted into grayscale (without color). The usage of greyscale sometimes provides a better quality, if you want to print the saved image on a black/white printer.
For both image formats there exists the possibility to define an "Image scaling factor". This is equivalent to scaling up (value > 1) or scaling down (value < 1) the saved image, based on the current size displayed in the program.

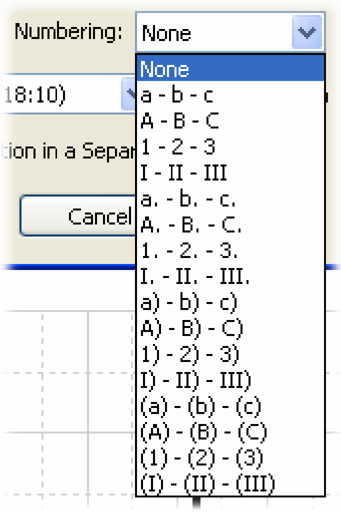
4.11.2 Save Gaze Pattern as Image

You can save the nine main gaze directions (default gaze pattern) shown in the 3D-view 111 as a combined image. To do so, select the menu item "Patient->3D-Model->Save Gaze Pattern as Image" in the main menu and the following dialog is opened, where you can choose the different settings.



With the "Type" box you can switch between left eye fixing and right eye fixing. By default the current fixation of the 3D-view is selected. The maximum gaze angle for the nine main gaze directions can be set in the "Angle" field.

A border can be drawn around the specific images of the 3D-view in the particular gaze positions. Its size can be set in pixel via the "Border Size" option. Furthermore, the color of the border can be adjusted with a click on the "Change..." button. If you want to switch of the border, you can set the border size to 0. If the specific gaze positions are saved to separate files, no border is drawn in and the options "Border Size" and "Border Color" are not used.

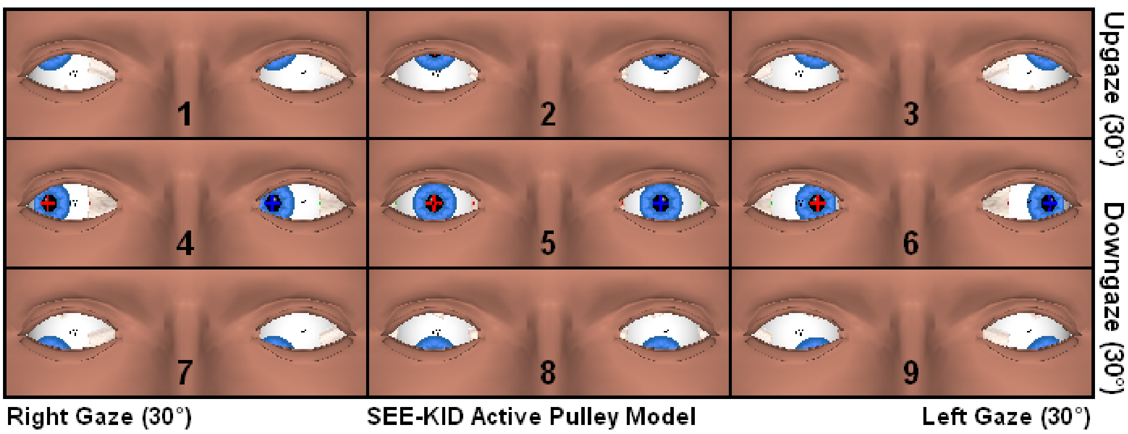


Via the "Numbering" option you can choose if you want to include a number or a character in every image. The numbering is thereby displayed in the lower middle region of each gaze position. You can choose of plenty of different numbering types. If you do not want a numbering, select "None".

If you select the "Show Caption" option you can specify, if the image should contain a textual description of the particular gaze directions as well as the currently selected model.

With the drop down box "Resolution" you can select the size of the combined image in pixel. This list contains the "name" of the resolution (e.g. "VGA"), the horizontal and vertical size of the resolution in pixel (e.g. 640x480) as well as the aspect ratio (width-to-height ratio, e.g. 4:3). Via the "Current Size" resolution you can achieve that the current size of the 3D-view is used for the size of each **single** gaze position. If the option "Save Each Gaze Pattern in a Separate File" is activated, the 3D-view of each gaze position is saved to a separate file and not as a combined image.

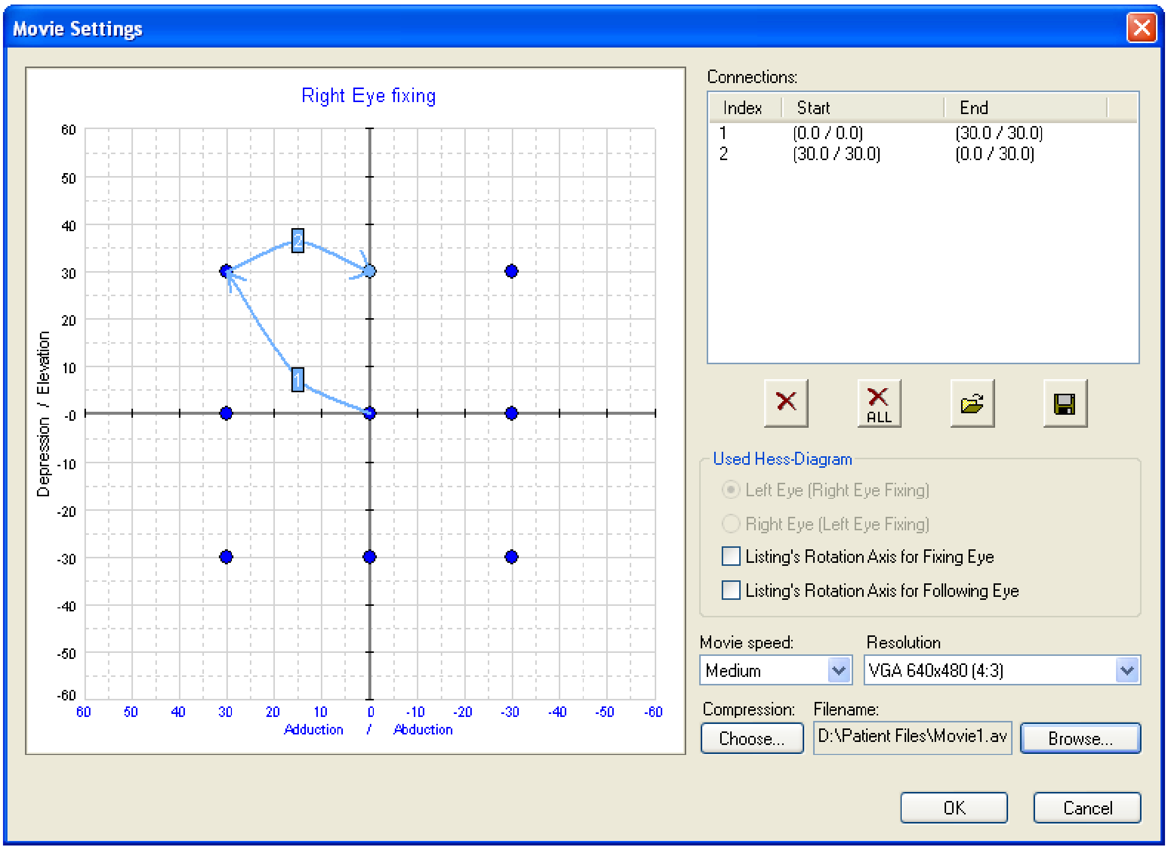
The dialog to save images 149 is displayed after you have clicked on the "Save..." button. Now proceed as it is described in "Save as Image" 149. If the option "Save Each Gaze Pattern in a Separate File" is activated, the image number (from 1 to 9) as well as the particular gaze position of the fixing eye (e.g. +30 +30 for 30° adduction and 30° elevation) are appended automatically to the denoted filename.



4.11.3 Create Movie

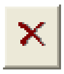
Another option to export data from SEE++ is the function to save the current simulation results as an AVI movie for better illustration. Thereby the "virtual patient" (in the 3D-view 111) sequentially looks at different gaze positions. These movies can be played in numerous players (Windows® Mediaplayer, etc.) and in presentations (e.g.: PowerPoint®).

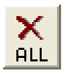
In order to create a movie it is necessary that at least one simulation result (right eye fixing and/or left eye fixing) is displayed in one of the diagram-windows of SEE++. Otherwise the function in the main menu 79 under "Patient->3D-Modell->Create Movie" is deactivated. That is because the fixation points of the gaze pattern 91 for right eye fixing or left eye fixing are used as a template for the creation of the movie. If both fixations are displayed in the diagram-windows of SEE++ before the dialog is opened, you can choose between right eye fixing and left eye fixing via the "Used Hess-Diagram" box.



Before you can create a movie, you first have to define which fixation positions in which sequence the "virtual patient" should look at ("animation path"). For this purpose select any fixation position of the used Hess-diagram (blue point) by left-clicking on the appropriate point. Then move the mouse while keeping the left mouse button pressed over any other fixation position and release the mouse button as soon as the target point is colored light blue. Now an arrow with the number "1" is drawn in between the two fixation positions. You can now always draw a new arrow from the last selected point to another fixation position over and over again. The arrows are thereby numbered ascending and the drawn in connections are additionally displayed in the list on the right hand side of the dialog. If you left-click on one of the connections in the list, the appropriate arrow is marked red. The arrows define the sequence and the selection of the fixation positions, which the "virtual patient" looks at in chronological order for the creation of a movie. Thereby for each fixation position the position of the following eye is calculated. That way the characteristics of a possible pathological situation can be dynamically illustrated in a clear way.

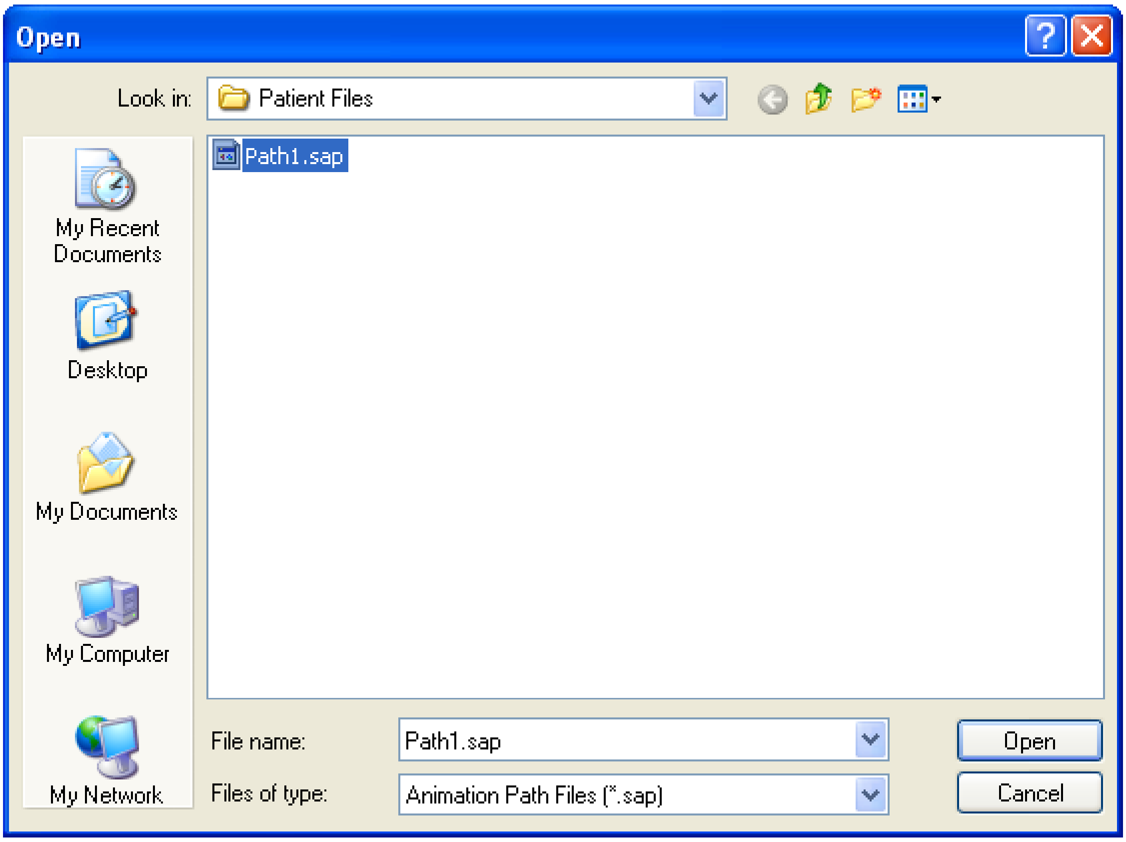
To make it easier to create an animation path, the following functions are provided:


With a click on this button the last drawn in arrow (the arrow with the highest number) is deleted. This button has no functionality, if no arrows exist.

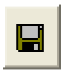


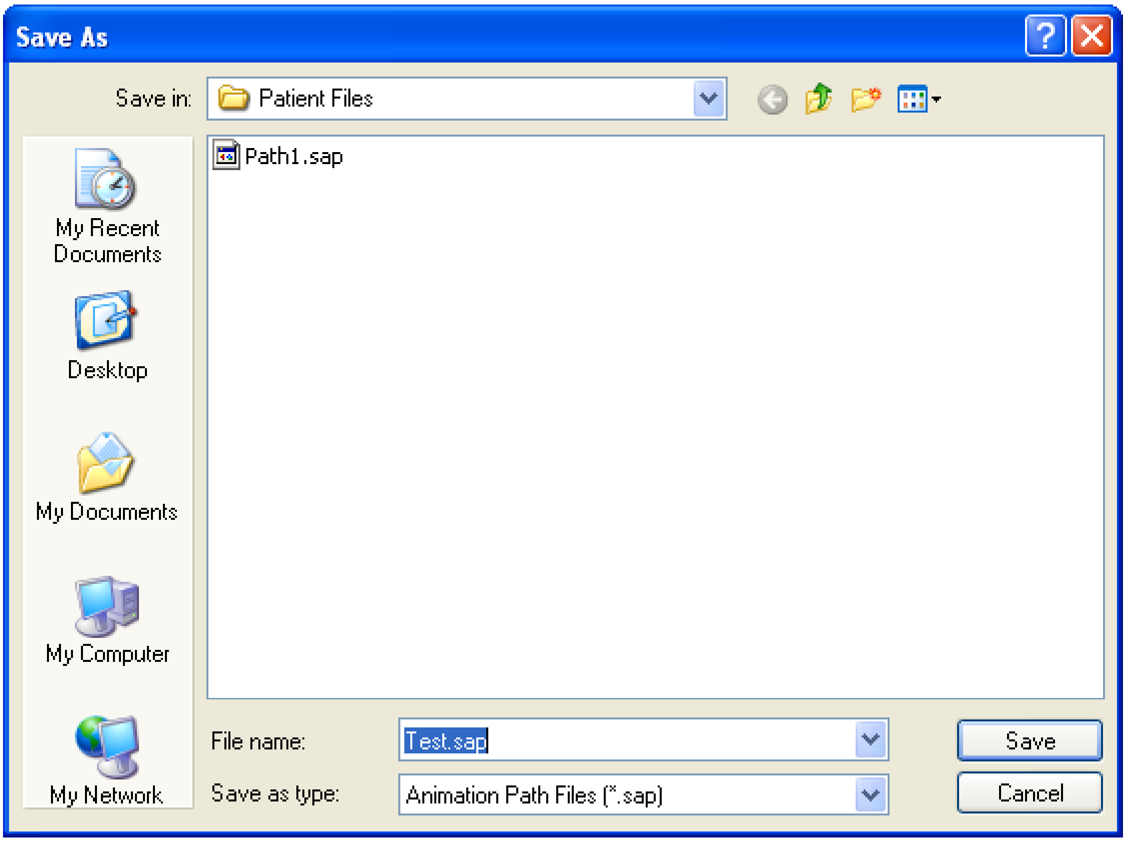
This button deletes all existing arrows.


With this function you can load an animation path from a file. When loading an animation path file, the current animation path is replaced by the one from the file.



After clicking on the button for the loading of an animation path, the dialog for the selection of an animation path file is opened. These files have the extension ".sap". Navigate to the particular directory and click on the .sap file you want to load. Afterwards click on "Open" or "Öffnen" to load the file. If you push the "Cancel" or "Abbrechen" button, no file is loaded and the current animation path is retained unchanged.


If you have drawn in an animation path, you can use this function to save it to a file. Files that save animation paths have the extension ".sap" and can be loaded again anytime via the open function (see above).



After clicking on the button for the saving of an animation path, the dialog for the selection of the target directory and the filename is opened. Proceed like opening an animation path file by navigating to the particular directory and clicking the "Save" or "Speichern" button after naming the file.

A saved animation path is independent from the selected gaze pattern (right eye fixing and left eye fixing).

In the "Used Hess-Diagram" box you can also choose, if Listing's rotation axis 27 should be displayed for the fixing and/or the following eye in the movie. Additionally, you can choose a movie speed (slow, medium, fast), which specifies how fast the eye movement is done in the movie. The resolution determines the size of the movie and therefore the quality of the single frames of the movie (high resolution = better quality, but larger file). The list of the available resolutions contains the "name" of the resolution (e.g. "VGA"), the horizontal and vertical size of the resolution in pixel (e.g. 640x480) as well as the aspect ratio (width-to-height ratio, e.g. 4:3). Via the "Current Size" resolution you can achieve that the current size of the 3D-view 111 is used for the resolution of the movie.

Furthermore, you can configure the compression of the movie (via the button "Choose..." under "Compression") by selecting a specific codec. The selection of a codec determines the format, in which the movie is encoded and/or compressed. This codec has to be installed on the computer where you want to play the movie. By default some codecs are installed in Windows® for the creation of movies, but they provide only limited quality. Therefore, the "XviD"-Codec (www.xvid.org) is installed together with SEE++. This codec is free for use and provides a good movie quality with high compression. Furthermore, due to the automatic installation of the codec together with SEE++, it is guaranteed that the movies created with SEE++ can be played on any computer where SEE++ is installed (unless a different codec was manually selected for the creation of a movie).

Only change the default codec (XviD), if you are absolutely sure. Your movies could have bad quality or possibly cannot be played on a different computer.

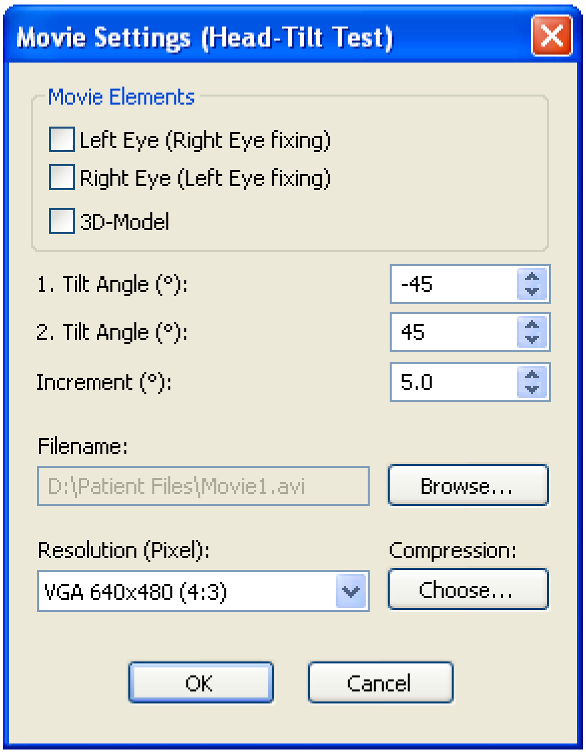
You have to specify a file name and a directory before you can create the movie. Via the "Browse..." button the default dialog for saving AVI files is opened. Navigate to the directory where you want to save the movie file and name the movie file appropriately. The file extension of a movie is always ".avi". The selected directory as well as the chosen name are displayed in the field below "Filename" after the default dialog for saving AVI files has been closed with a click on "OK".

If you have finished all your settings, confirm the dialog with "OK" and the movie will be created. With a click on "Cancel" the dialog is closed and no movie is created. The current animation path remains set until SEE++ is quit, independently of the button you used to close the dialog ("OK" or "Cancel").

If you want to influence the creation of a movie regarding the available fixation points, you have to change the gaze pattern 91 of the corresponding fixation. If you want to cancel the creation of a movie, push the "ESC" key during the creation process. The canceling can take several seconds! After canceling the creation, those parts of the movie, which were already created until the process was canceled, are stored in the AVI file.

4.11.4 Create Movie for Head-Tilt Test

The "Create Movie for Head-Tilt Test" function offers the possibility to create AVI movies in a specific gaze position with changing head-tilt 123. Therefore, you can dynamically and very clearly illustrate a pathological situation, which shows a change in the Hess-Lancester test in different head-tilt 123 positions. To access the dialog with the movie settings, select the menu item "Patient->3D-Model->Create Movie for Head-Tilt Test" via the main menu 79.



In the "Movie Elements" box you can select the elements you want to include in your movie. The two Hess-diagrams for right eye fixing and left eye fixing can only be selected, if the appropriate simulation result were already displayed in one of the diagram-windows of SEE++ before the dialog was opened. The "3D-Model" can always be selected and is included into the movie exactly as it is currently displayed in the 3D-view 111. You have to select at least one movie element to be able to create a movie.

The arrangement of the specific movie elements depends on the elements you have selected. If you have included both Hess-diagrams into the movie, they are always displayed side by side. If the 3D-model is additionally integrated into the movie, there exist two different cases. In the first case both Hess-diagrams are displayed and the 3D-model is displayed above them. In the second case only one Hess-diagram is displayed and the 3D-model is displayed on the right hand side of the specific Hess-diagram.

During the creation of the movie, the head of the "virtual patient" is always first moved into the direction of the "1. Tilt Angle" and afterwards into the direction of the "2. Tilt Angle". At the beginning, the head-tilt is always set to 0° and the increment can specified set via the "Increment" field. The larger the value for the increment, the faster appears the head movement in the movie. The smaller the increment, the slower is the movement. Therefore, you can influence the movie speed by changing the increment.

The resolution determines the size of the movie and therefore the quality of the single frames of the movie (high resolution = better quality, but larger file). The list of the available resolutions contains the "name" of the resolution (e.g. "VGA"), the horizontal and vertical size of the resolution in pixel (e.g. 640x480) as well as the aspect ratio (width-to-height ratio, e.g. 4:3). Via the "Current Size" resolution you can achieve that the current sizes of the 3D-view 111 and of the Hess-diagrams 116 are used for the resolution of the movie (depending on which movie elements are selected).

Furthermore, you can configure the compression of the movie (via the button "Choose..." under "Compression") by selecting a specific codec. The selection of a codec determines the format, in which the movie is encoded and/or compressed. This codec has to be installed on the computer where you want to play the movie. By default some codecs are installed in Windows® for the creation of movies, but they provide only limited quality. Therefore, the "XviD"-Codec (www.xvid.org) is installed together with SEE++. This codec is free for use and provides a good movie quality with high compression. Furthermore, due to the automatic installation of the codec together with SEE++, it is guaranteed that the movies created with SEE++ can be played on any computer where SEE++ is installed (unless a different codec was manually selected for the creation of a movie).

Only change the default codec (XviD), if you are absolutely sure. Your movies could have bad quality or possibly cannot be played on a different computer.

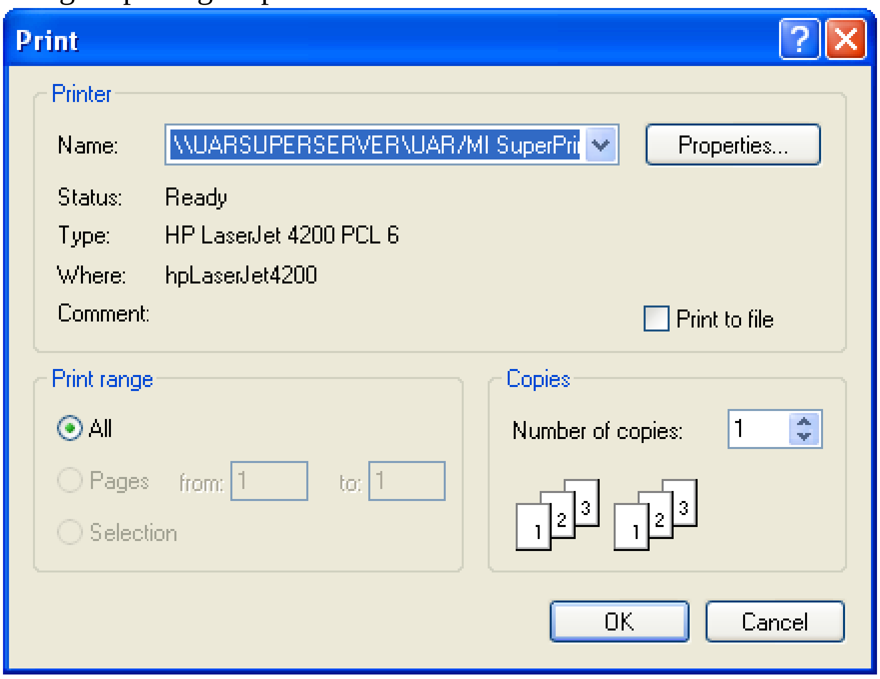
You have to specify a file name and a directory before you can create the movie. Via the "Browse..." button the default dialog for the saving of an AVI file is opened. Navigate to the directory where you want to save the movie file to and name the movie file appropriately. The file extension of a movie is always ".avi". The selected directory as well as the chosen name are displayed in the field below "Filename" after the default dialog for saving AVI files has been closed with a click on "OK".

If you have finished all your settings, confirm the dialog with "OK" and the movie will be created. With a click on "Cancel" the dialog is closed and no movie is created.

If you want to cancel the creation of a movie, push the "ESC" key during the creation process. The canceling can take several seconds! During the creation of a movie for the head-tilt test, SEE++ automatically performs two passes to determine the maximum expansion of the Hess-diagrams. If you cancel the creation of the movie during the first cycle, no file is created. If the creation is canceled during the second cycle, those parts of the movie, which were already created until the process was canceled, are stored in the AVI file.

4.11.5 Print

You can print a diagram 114 via its context menu and the 3D-view 111 via the main menu under "Patient->3D-Model->Print". After selecting the specific print function, the Windows® default dialog for printing is opened.



Select the printer you want to use and the number of copies in this dialog. Confirm the dialog with "OK" to start the printing. If you want to select a different default printer, you have to access the printer options dialog 147.

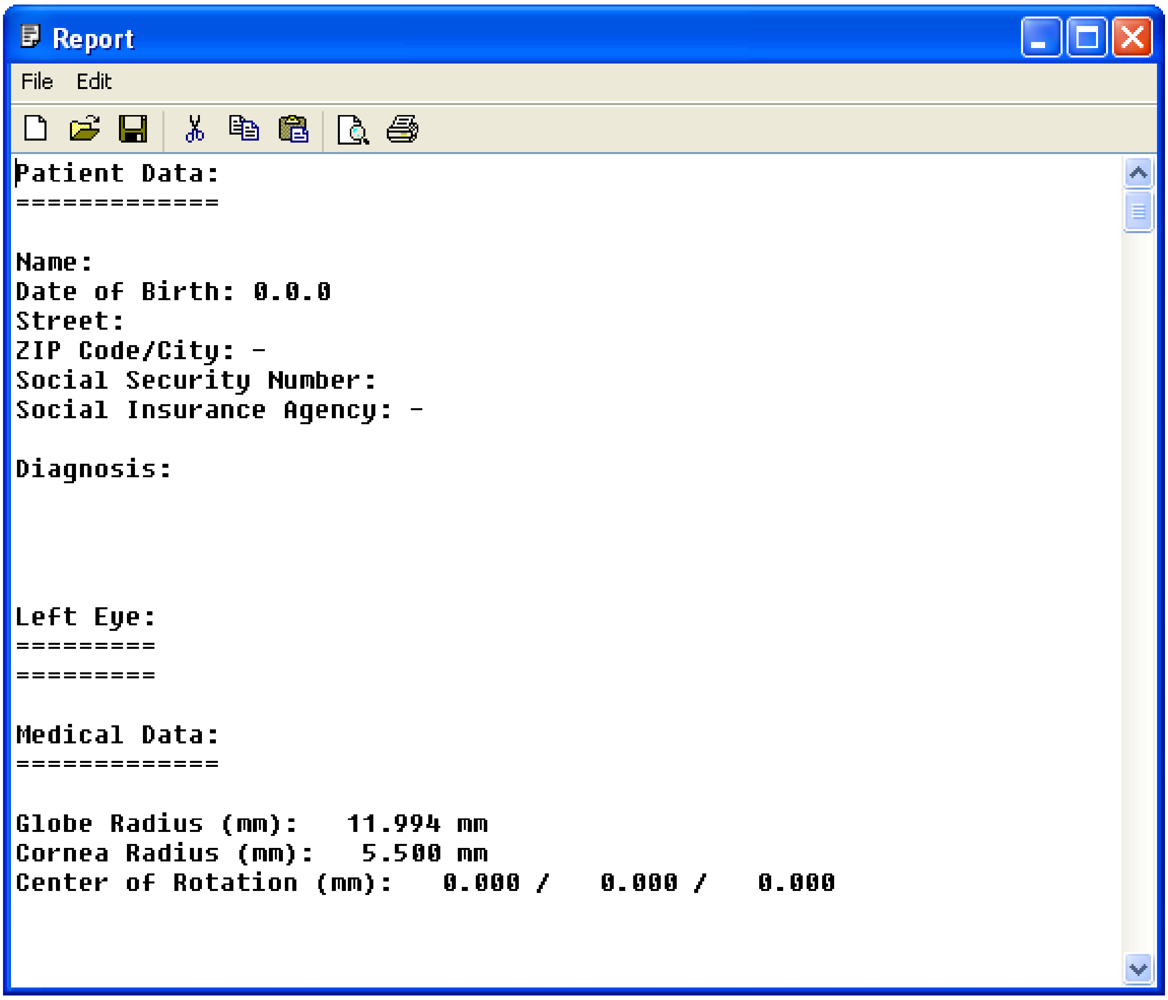
4.11.5.1 Print Preview

You can access the print preview of a diagram 114 via its context menu and of the 3D-view 111 via the main menu under "Patient->3D-Model->Print Preview". The print preview is a Windows® default dialog and allows to preview the content to be printed. The specific diagrams are automatically adjusted to the selected paper format.

If you want to define a smaller print format or a different print layout, modify the printer's paper size 147 or save the images as files 149 and use e.g. Microsoft Word® or a similar program to design your own printout.

4.11.6 Report

The report provides a complete list of all parameters of the currently active simulation model and of their appropriate values. You can access this function via the Treeview under "Report" or via the main menu under "Views->Report". A window is opened containing the report in textual form similar to the activity log 104 or the Stateviewer 118 report.



You can save or print this textual report of the whole simulation model with the aid of the displayed editor. The report window is an adequate text editor similar to the enclosed Microsoft Windows® editor.

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