Non-Deterministic Optimization to account for Anatomical and Physiological Variability in Strabismus Surgery Modeling

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Abstract

Current computerized strabismus models do not account for anatomical and physiological variability. This study explored whether it is useful to account for this variability by applying the Bounded-but-Unknown Uncertainties (BUU) optimization algorithm to the Simonsz-Robinson model and whether other uncertainties should also be accounted for (i.e. surgical precision).

Application of BUU optimization seems beneficial, but is currently hampered by the lack of knowledge on the most influential parameter. In future development of strabismus models other uncertainties should also be accounted for as there influence is considerable.

Introduction

Five percent of the population suffers from strabismus[1], commonly known as crossed-eyes, which is remedied by surgically shortening of one eye muscle and (quasi-) lengthening of its antagonist. While, in routine strabismus surgery, empirical guidelines and experience are used to determine the procedure and amount of surgery, in complex cases it can be very difficult to conceptualize the consequences of these alterations. In these cases computerized strabismus models can be useful. Current models do not account for the variability of anatomical and physiological parameters that constitute the model, instead they employ averages.

This study explored whether it is useful to account for this variability by applying the Bounded-but-Unknown Uncertainties (BUU) optimization algorithm[2] to the Simonsz-Robinson model[3]. In a preanalysis all uncertainties involved in strabismus surgery where determined.

Methods

All uncertainties influencing the results of strabismus surgery were categorized in:

1. Anatomical and physiological variation
2. Sensoric influences like depth vision
3. Measurement errors in preoperative examination
4. Measurement errors during surgery
5. Measurement errors in postoperative examination

In an exploratory analysis uncertainties of Category 4 and, to a lesser extent, 3 and 5 were quantified by comparing the actually measured effect of surgery with the surgery prescribed by orthoptists. Recent data (n=85) from a prospective multicenter strabismus-surgery study was consulted to derive the actual effect [°/mm] of horizontal muscle surgery, measured under controlled circumstances. To derive a clinical guideline for surgery prescription a questionnaire was put to 200 Dutch orthoptists asking them the amount of lengthening and shortening they would prescribe in standard cases. This concerned three 4-year-old children with congenital esotropia (congenital esotropia is a type of strabismus is when the child develops crossed eyes by six months of age.) of 10°, 15° and 20°. In their advise orthoptists aim for 85% success which corresponds to the average plus one standard deviation (s.d.) of the actual effect.

Further study was limited to those uncertainties employed as variables in the model, which are the uncertainties of Category 1.

This problem was formulated as an optimization problem by defining an objective function whose minimum value corresponds to the optimal postoperative result. The objective function was rated by the angles of strabismus in primary position (gaze ahead, 50%) and, to a lesser extent in secondary positions (left, right, up and down gaze, each 12.5%), reflecting the clinical impression that patients are most bordered by double vision when looking straight ahead. Surgery was limited to two muscles per eye as is common practice.

To explore the applicability of BUU optimization the influence of parameters on surgical advise has been analyzed in a simulation of congenital esotropia and a superior oblique palsy (the superior oblique muscle rotates the eye both downward and inward toward the nose). All combinations of two parameters have been varied between their feasible upper and lower bounds.

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Deterministic optimization (using average values of parameters) was carried out by varying the amount of surgery on each combination of two muscles and evaluating the postoperative result for 20° of congenital esotropia. Accordingly the optimization resulted in the surgical advise corresponding to the lowest possible value for the objective function. Thereafter BUU optimization was carried out for the same case. For each amount of surgery, combinations of the most prominent parameters were examined to find the set of values that provided the poorest postoperative result. This process is also known as anti-optimization. Accordingly this optimization resulted in the best advise for the worst possible combination of parameters.

Results

The outcome of the questionnaire among Dutch orthoptists showed (Table 1) that in the Netherlands eye muscles are advised to be lengthened or shortened less then needed considering the actual effect measured.

angle of strabismus	10°	15°	20°
Dutch orthoptists [°/mm]	1.64	1.78	1.98
average actual effect [°/mm]	1.17	1.33	1.50
average actual effect +1s.d.	1.57	1.73	1.90

Table 1: *Surgery suggested by Dutch orthoptists, average actual effect of surgery and average effect plus one standard deviation (85% of measured cases).*

There is a distinct difference between the advise by Dutch orthoptists and the actual effect of surgery, the advise is affected by all categories of uncertainties, while Category 4 is excluded from the study on the actual effect. An additional effect is caused by the general fear for overcorrection. Overcorrection often results in double vision.

In contradiction to research on other models[4][5], this model was sensitive to uncertainties in Category 1. Pre-analysis for BUU optimization showed that the spring constant in Passive Rotation (PR) of the eye (all six muscles detached) was the most influential parameter. The spring constant of the Innervated Muscles (IM) was second, the relative spring constant of vertical recti and oblique eye muscles third. The influence of all other parameters could be neglected. Furthermore, variation of both PR and IM showed that at low values of PR (in the order of 0.1 g/°) the influence of IM is minimal, while at high values of PR (in the order of 1 g/°) a substantial influence of IM on the advised surgery is present (Fig.1).

For horizontal strabismus optimization advised surgery on two horizontal muscles in varying amounts. As the model considers the eye muscles as linear springs, no distinction is made between for instance a large lengthening and minor shortening, and equal alterations. In practice this would result in incomitance. The summed amount of both muscle alterations was therefore opted for as decisive design variable for optimization and was found to be approximately constant for each run.

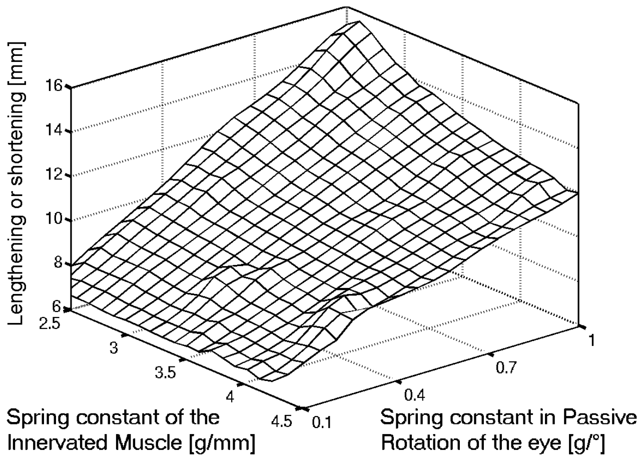

Figure 1: *Influence of PR and IM on the advised lengthening and shorting of two horizontal eye muscles*

The advise resulting from BUU optimization was found to be more conservative then from deterministic optimization. For the clinical case of congenital esotropia the model was only sensitive to variation of PR and IM. Anti-optimization for this case always resulted in one specific combination of these uncertainties, namely the lower-bound of PR and the upper-bound of IM. It is unclear yet whether this set of values will be found for other clinical cases (i.e. superior oblique palsy), when including the relative spring constant of the vertical recti and oblique eye muscles as uncertainties.

Discussion

In this study the application of BUU optimization for congenital esotropia has been demonstrated. The parameters prominent in the Simonsz-Robinson model differ considerably in reality. Therefore application of BUU optimization appears to be useful.

In the past, research has well defined the boundaries of IM [6]and the relative spring constant of vertical recti and oblique eye muscles[7]. The value for PR, the most prominent parameter in the model, has never been measured in vivo[1] or postmortum[2]. Due to the lack of knowledge on PR the amount of lengthening or shortening suggested by the BUU optimization can not clearly be defined (Fig. 1) and variations in the advise caused by Category 1, which was studied, can not be determined. The remaining categories can therefore not be quantified.

Conclusions

Application of optimization with Bounded-but-Unknown-Uncertainties for Category 1 seems beneficial, but is currently hampered by the lack of information on the spring constant in Passive Rotation of the eye. In future development of strabismus models uncertainties of other categories should also be accounted for as there influence is considerable.◀

[1] Cutting all the six muscle of the eye results in the loss of the eye.

[2] The mechanical characteristics of the tissue surrounding the eye change very rapidly after death.

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