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# Directional Deep Brain Stimulation

WSSFN Webinar August 2018

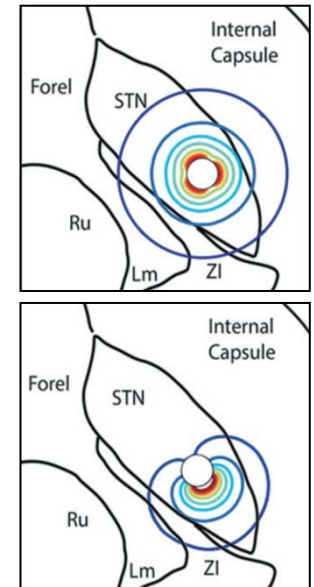
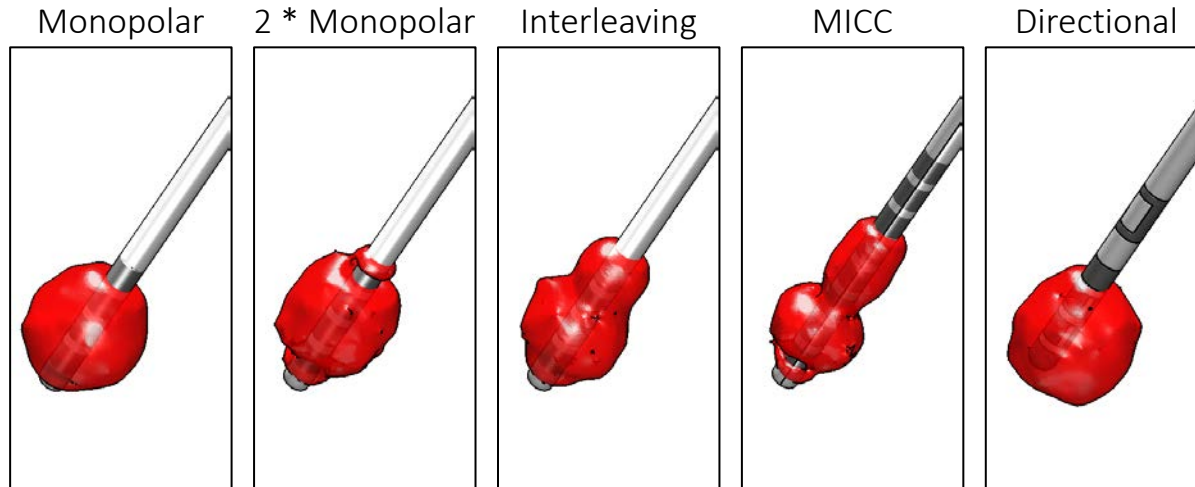
29.08.2018 | Till A. Dembek | Department of Neurology | University Hospital of Cologne

# Agenda

- The rationale behind directional DBS
- Clinical trials of directional DBS
- Programming directional DBS
- Orientation of directional leads
- Computer-assisted programming

# The Rationale Behind Directional DBS

- DBS aims at spatially specific stimulation of a neuroanatomical target structure
- Current-spread into adjacent structures should be minimized



Pollo et al. 2014

# Agenda

- The rationale behind directional DBS
- **Clinical trials of directional DBS**
- Programming directional DBS
- Orientation of directional leads
- Computer-assisted programming

# Clinical Trials of Directional DBS

- Short-term, 'monopolar review' studies
- Comparison between directional to circular DBS

Study	Design	N	Lead	Target	Side-Effect Threshold	Efficacy Threshold	TW increase
Contarino 2014	Intraoperative, double-blind	8	Sapiens	STN	↑	↔	n.a.
Pollo 2014	Intraoperative, double-blind	13	Aleva	STN,VIM	↔	↓	0.6 mA
Steigerwald 2017	Retrospective	7	BSCI	STN	↑	↔ (↓)	0.4 mA
Dembek 2017	Prospective, double-blind	10	BSCI	STN	↑	↔	1.0 mA
Rebelo 2017	Retrospective	8	Abbott	VIM	↔	↓	0.9 mA
Choe 2018	Prospective	8	Abbott	VIM	↔	↔	n.a.

# Clinical Trials of Directional DBS

- Case reports:
  - Combining directional and bipolar stimulation (Reker et al. 2016)
  - Combining two neuroanatomical targets (Falconer et al. 2018)

## CAVE:

- No long-term studies
- No comparisons against standard DBS devices

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# Programming Directional DBS

## General Considerations:

- Routine employment of directional DBS?
- Routine monopolar review of directional electrodes?

## Pros:

- Therapeutic current might be smaller with directional DBS
- Side-effects might occur less frequently with directional DBS

## Cons:

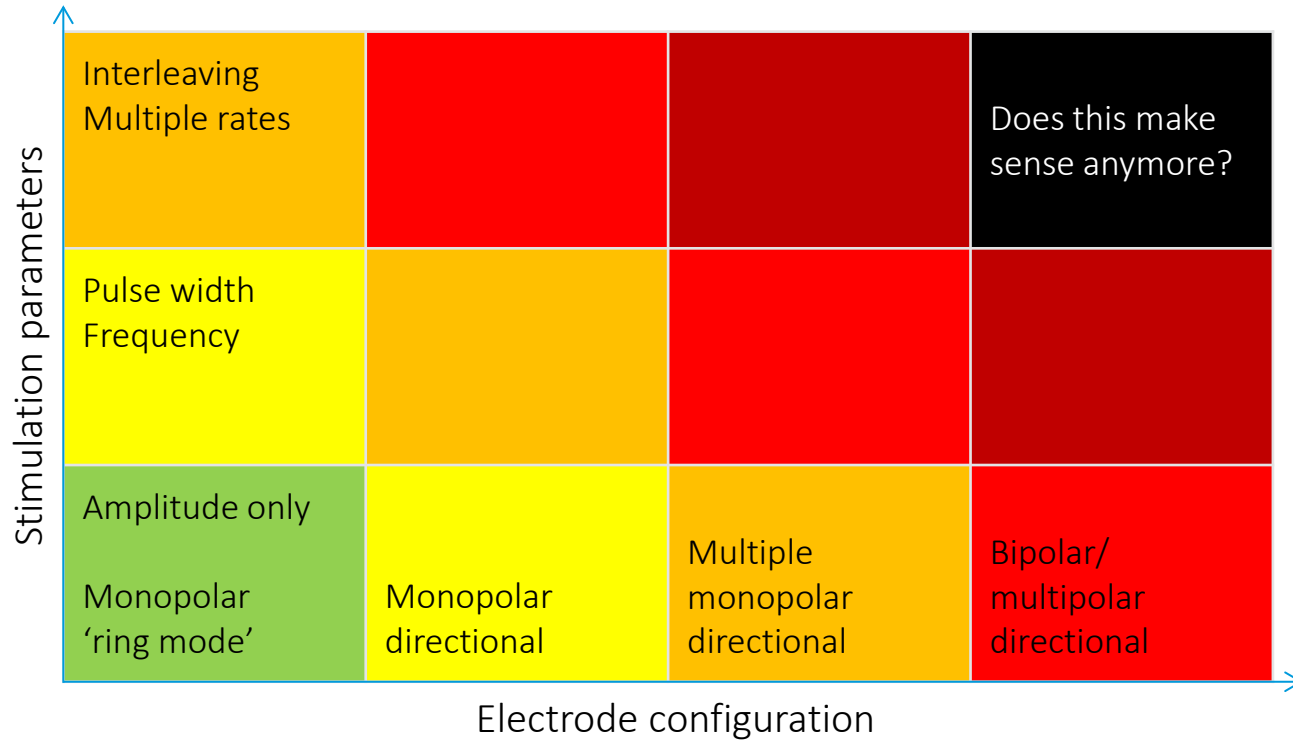
- Effects might be comparable in a well-placed lead
- Patient burden, time, money

# Programming Directional DBS

Two-step approach:

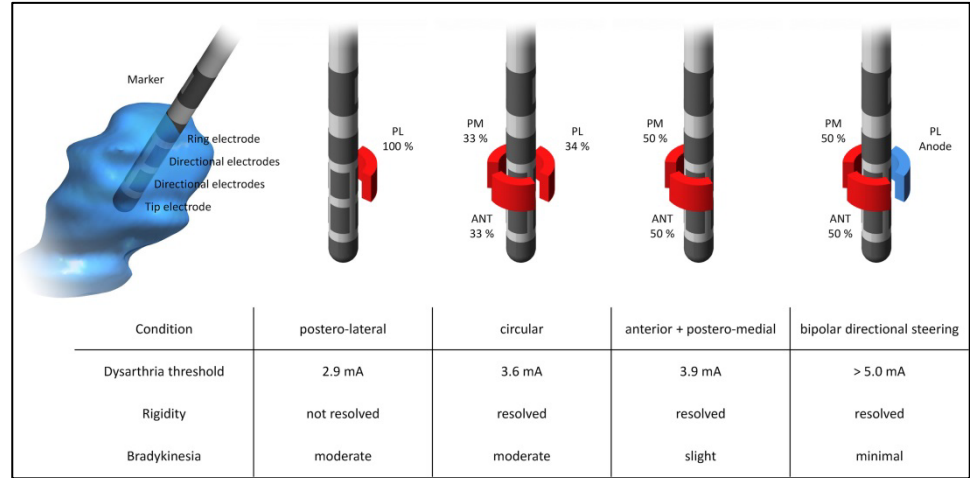
- Initial monopolar review and programming in “ring-mode” only
- Routine utilization of amplitudes, pulse widths, and frequencies
- Monopolar Directional DBS in case of limiting side-effects
- More complex multiple-electrode configurations as escalation strategy

# Programming Directional DBS



# Bipolar Directional DBS

- Reker et al. case report:
  - Increase dysarthria thresholds
  - Resolved motor symptoms
  - Lead to psychiatric side-effects



Reker et al. 2016

- Steffen et al. (submitted, n = 14):
  - No general superiority to monopolar directional DBS
  - No general superiority to conventional bipolar DBS

# Agenda

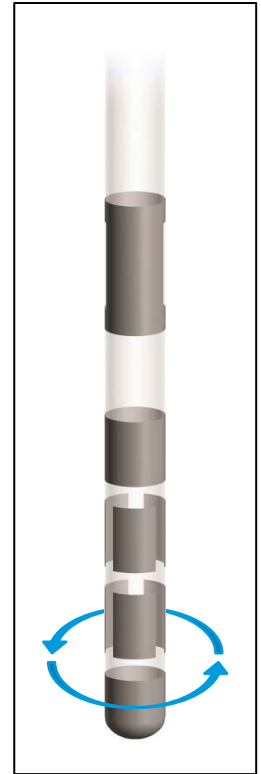
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# Lead Orientation

- New degree of freedom
- No specialized stereotactic equipment
- 'Fiddly' handling
  - Rotation by 0.1 mm -> Orientation change of 10 °
  - Leads are not stiff objects
- Important for informed programming

## Questions:

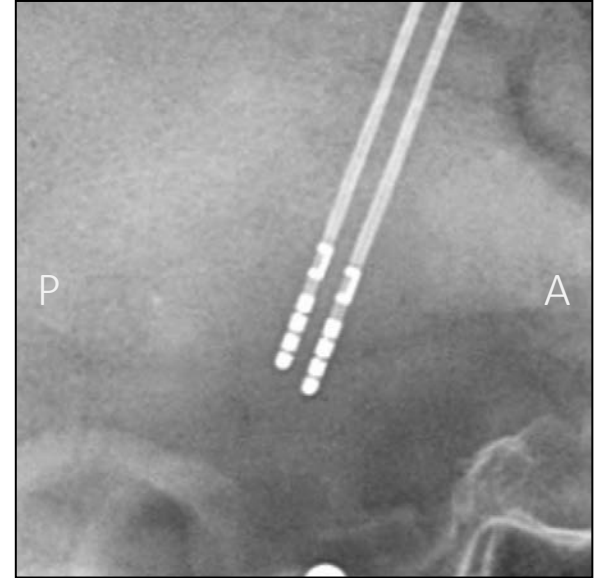
- Can lead orientation be adequately adjusted intraoperatively?
- How can we measure lead orientation?



# Quantifying Lead Orientation

## Visual Inspection

- Stereotactic marker provides raw guidance
- Accurate estimation not possible
- No accurate translation to patient anatomy



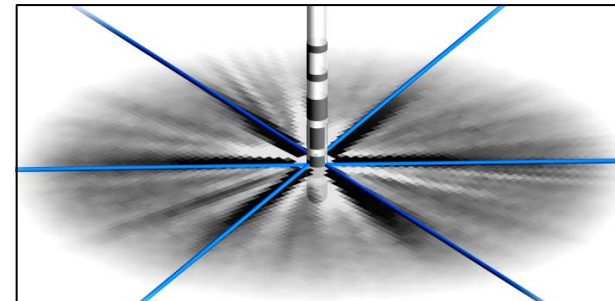
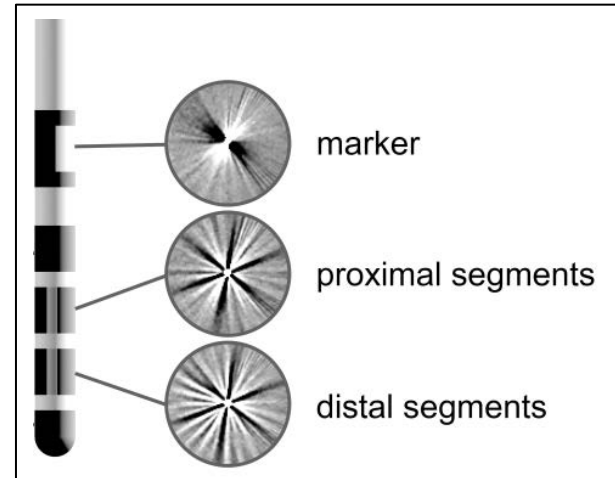
# Quantifying Lead Orientation

- Algorithms for different imaging have been proposed:

Study	Design	Modality	Accurate	Automatic	Translation to anatomy
Reinacher 2017	Phantom	Rotational Fluoroscopy	Yes	No	Difficult
Sitz 2017	Phantom	Stereotactic X-ray	Yes	No	Easy
Sitz 2017	Phantom	CT	Yes	No	Easy
Hunsche 2018	Phantom	Flatpanel CT	Yes	No	Moderate

# The Directional Orientation Detection (DiODe) Algorithm

- Based on Sitz et al. for postoperative CT
- Analyzes characteristic CT artifacts
- Phantom-validated  
(Hellerbach et al., under review)
- Automatic workflow
- Integrated into Lead-DBS toolbox  
([www.lead-dbs.org](http://www.lead-dbs.org))



Hellerbach et al. 2018 (under review)

# The Directional Orientation Detection (DiODe) Algorithm

The screenshot displays the MATLAB R2018a environment with the Lead-DBS software interface. The MATLAB editor shows a script for determining angles, and the Lead-DBS control panel is configured for processing a patient folder. The workspace window on the right lists various variables and their values.

```
449 % determine angle
450 count = 1;
451 % approach creating
452 shifts = [];
453 for k = -30:30
454     shifts(count) = k;
455     count = count + 1;
456 end
457 rolltemp = roll(dirl_angles(count), shifts);
458 dirl_angles(count) = [sum(intensity1(rolltemp))];
459 rollangles(count) = [sum(intensity2(rolltemp))];
460 dir2_angles = [sum(intensity2(rolltemp))];
461 clear rolltemp
462 count = count + 1;
463 clear rolltemp
464 end
465 count
466
467 [-, temp] = min(su
468 roll1 = rollangle
469 dir1_angles = es_g
470 dir1_valleys = ro
471 dir1_valleys(dir1
472
473 [-, temp] = min(su
474 roll1 = rollangle
```

**Lead-DBS v2.1.5** (Not for clinical use)

1. Load patient folder, specify electrode model and imaging method  
D:\TAR\LEAD\_TWEED\TWEED01  
Recent patients: CT

2. Import & assign images to standard NIFTI format (DICOM/NIFTI)  
Import: dcm2nix (Rorden; Li 2016) | Rename

3. Volume registrations  
**Coregister Volumes**  
CT to MRI method: Advanced Normalization Tools (ANTs)  
MRI to MRI method: SPM  
**Normalize Volumes**  
Advanced Normalization Tools (Avants 2008) | Settings  
**Brainshift correction**  
Coarse mask (Schöneckner 2008)  
**Check Results**

4. Surface Reconstruction (optional)  
**Extract Surface**  
Computational Anatomy Toolbox (CAT12)

5. Reconstruction of electrode trajectories (optional)  
**pre-Reconstruct**  
Method: PaCER (Husch 2017)  
Target: STN, GPi or VIM | Mask window size: auto  
 Localize DBS electrodes

6. Perform connectivity analysis (optional)  
**Lead Connectome** | Settings

7. Visualization  
MNI ICBM 2009b NLIN ASYM Space  
STN-Subdivisions (Accolla 2014)  
 Write out 2D | 2D Settings  
 Render 3D | Import FS

CT-volumes have been normalized with:  
Advanced Normalization Tools (Avants 2008)  
Trajectory information present in folder. Will be overwritten if 'Reconstruct' is set.

**Run** | **Export Code**  
Patient Directory | Manual

Name	Value
extractradius	30
finalpeak	328
folder	'D:\TAR\LEAD_TWEED\TWEED01'
head_mrm	[-16.9502; -162.4320; 657.2490; 1]
head_native	[11.9375; -12.2183; 3.2340; 1]
head_lv	[237.1124; 224.9816; 124.9181; 1]
k	420x500x2 uint8
intensity	1x360 double
intensity1	1x360 double
intensity2	1x360 double
marker_mm	6
marker_vx	[-13; -159; 666; 1]
markerfit	[249; 232; 142; 1]
markerposition	1x360 double
options	1x1 struct
outputVideo	1x1 VideoWriter
peak	[148 328]
peakangle	5.7072
peakangle_corr	-0.5422
pitch	0.3602
pidm	[0.4648 0.4648 0.5000]
radius	16
reco	1x1 struct
reg2org	1x1 struct
roll	-0.5422
rollangles	1x62 double
shifts	1x62 double
side	1
sides	1x62 cell
sumintensity1	1x62 double
sumintensity2	1x62 double
supervised	0
tail_mrm	[-14.5854; -160.5000; 662.3782; 1]
tail_native	[14.5616; -10.8242; 8.4465; 1]
tail_lv	[252.0251; 229.1178; 135.1765; 1]
trmat_org	4x4 double
trmat_reg	4x4 double
trmat_reg2org	4x4 double
trmat_vs2mrm	4x4 double
tol	1.0000e-04
univector_mrm	[0.3962; 0.3237; 0.8592; 0]
valley	[58 238]
vector	360x2 double
vector1	360x2 double
vector2	360x2 double

# Lead Orientation in Clinical Reality

Study in  $n = 100$  patients and  $n = 198$   
directional leads:

- Lead orientation can deviate up to  $90^\circ$
- Deviations of  $> 60^\circ$  in 10% of the leads

Figure removed from online version

Dembek et al. 2018 (in preparation)

# Lead Orientation in Clinical Reality

Study in n = 100 patients and n = 198 directional leads:

- Lead orientation can deviate up to 90 °
  - Deviations of > 60 ° in 10% of the leads
  - Independent of neuroanatomical target
  - Independent of stereotactic frame and intraoperative imaging
- Postoperative verification strongly recommended!

Figure removed from online version

Dembek et al. 2018 (in preparation)

# Agenda

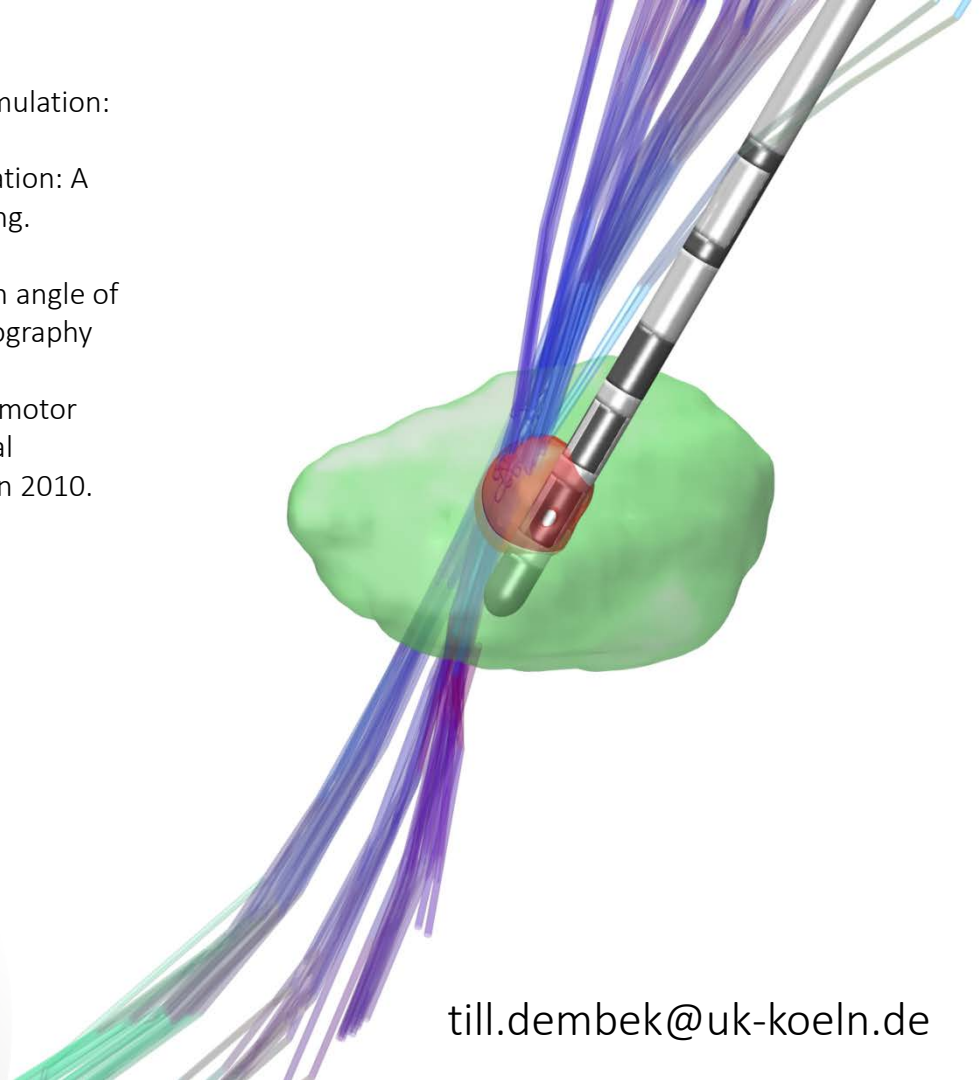
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# Conclusion

- Directional DBS...
  - increases acute side-effect thresholds
  - decreases acute efficacy thresholds
  - increases the therapeutic window...but only to a certain degree
- No data regarding long-term benefits
- Lead orientation should be analyzed postoperatively
- Directional DBS increases the complexity of DBS programming
- Programming based on functional hotspots might assist clinicians

#### Figure References:

1. Pollo C, Kaelin-Lang A, Oertel MF, et al. Directional deep brain stimulation: an intraoperative double-blind pilot study. *Brain* 2014.
2. Reker P, Dembek TA, Becker J, et al. Directional deep brain stimulation: A case of avoiding dysarthria with bipolar directional current steering. *Parkinsonism Relat. Disord.* 2016.
3. Sitz A, Hoevels M, Hellerbach A, et al. Determining the orientation angle of directional leads for deep brain stimulation using computed tomography and digital x-ray imaging: A phantom study. *Med. Phys.* 2017.
4. Frankemolle AMM, Wu J, Noecker AM, et al. Reversing cognitive–motor impairments in Parkinson’s disease patients using a computational modelling approach to deep brain stimulation programming. *Brain* 2010.



Thank you!