

Computer Modelling of Flow, Shape and Tissue Stress/Strain in Intracranial Aneurysm

Alberto Marzo, Derek Sweeney, Martin Murphy

Demonstration layout



- IDAC company background
- IAs clinical background
- role of haemodynamics in IAs
- @neurIST technology
- demonstration of unstented case
- demonstration of stented case
- SBNS study
- what next

IDAC company background



- CAE Consultants, established in 1997
- 5 Employees
 - Derek Sweeney
 - Dr. Paul Fanning
 - Bob Moore
 - Barbara Leichtenstern
 - Dr Alberto Marzo
- In collaboration with partners in 3 successful European projects, we have developed a range of web-enabled simulation applications aimed at Medical Device Manufacturers and Clinical Researchers
- @neurIST (European Project) finished in March 2010. We are now trying to market the tools developed.
- We supported Martin Murphy in his Research work (poster won a best in section prize at the SBNS meeting)
- Purpose of this meeting is to show you what can be done and then explore possibility of Research projects etc

@neurIST





Members of the consortium

- Multidisciplinary European initiative funded by the EU*
- ✓ 4-year project, budget 17 million €
- Neurosurgeons, neuroradiologists, epidemiologists, engineers, biologists and computer scientists from 32 EU institutions
- Industrial, academic and medical institutions
- Aim: improve current management of intracranial aneurysms



Clinical background



- Aneurysmal SAH major cause of morbidity and mortality with high rates of case fatality (40-50%) [1,2]
- Management of <u>unruptured</u> IAs remains controversial topic in Neurosurgery
- Most aneurysms do not rupture [2], etiological/pathological factors responsible for rupture remain poorly understood
- Morbidity and mortality from operative/endovascular treatment, prompts need for better management protocol
- Evidence from literature suggests an emerging role of haemodynamics, shape and tissue stress/strain in aneurysmal pathogenesis [3,4]

⁽¹⁾ Inagawa Stroke 2001, ⁽²⁾ ISUIA N Eng J Med 1998, ⁽³⁾ Sekhar et al. Neurosurgery 1981, ⁽⁴⁾ Ujiie et al. Neurosurgery 1999

Role of haemodynamics

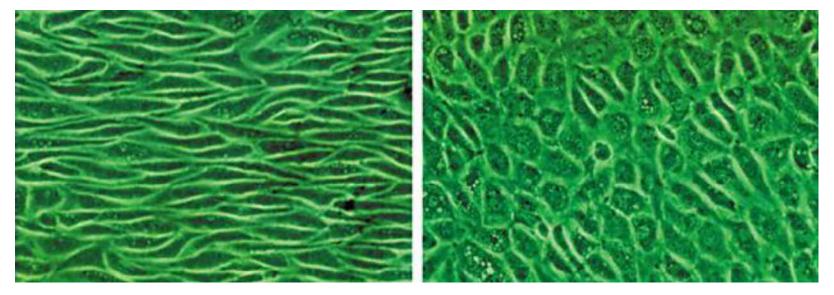


Wall Shear Stress (WSS)

- WSS definition: frictional tangential force exerted by blood flow on endothelial layer
- Supra- and infra-physiological values of WSS have been associated to endothelial damage, aneurysm formation and rupture [1]

normal WSS

infra-physiological WSS



(1) Malek et al JAMA 1999

Role of haemodynamics



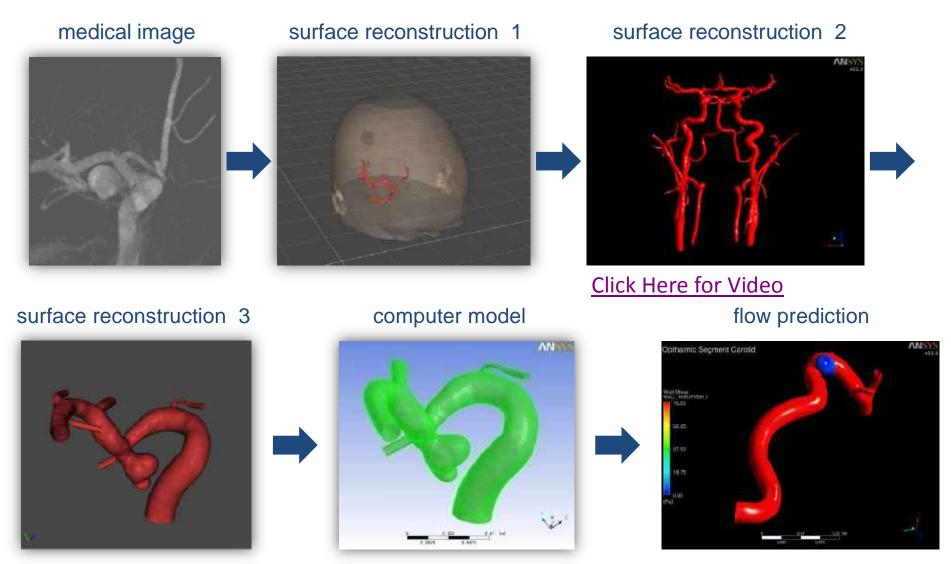
Hemodynamic	Iı	ntracranial Aneur	ysm	Proposed mechanism(s)	References
factors	Initiation	Growth	Rupture	-	
Dynamic					
Wall Shear Stress (WSS)	High	Low	Low	 Increased WSS increases the production of MMP-13 which in turn leads to vessel wall damage Decreased WSS increases iNOS synthesis- NO induced damage to vessel wall Low WSS increases endothelial condition and economic in 	Gao et al (2008), Fukuda et al (2000), Meng et al (2007), Shojima et al (2004), Jou et al (2008), Malek et al (1999), Ujie et al (1999), Boussel et al (2008),
Oscillatory Shear Index (OSI)	High/Low	High	High	proliferation and apoptosis Degenerative changes in endothelium	Mantha et al (2006), Glor et al (2004), Goubergrits et al (2008)
Jet of Blood Stream	Impingement	Impingement	Impingement	Localized endothelial cell injury	Foutrakis et al (1999), Cebral et al (2005), Cebral et al (2008)
Flow Pattern	-	-	Complex	Statistical association	Cebral et al (2005), Cebral et al (2008)
Hydrostatic					
Pressure	High	High	High	Passive yield/ water hammer effect	Inci and Spetzler (2000), Morimoto et al (2002), Steiger et al (1989)

NB: WSS; wall shear stress, MMP-13; matrixmetalloproteneases-13, iNOS; inducible-nitric oxide synthase, NO; nitric oxide, OSI; oscillatory shear index

Singh PK, Marzo A et al Comput Intell Neurosci 2009

@neurIST technology



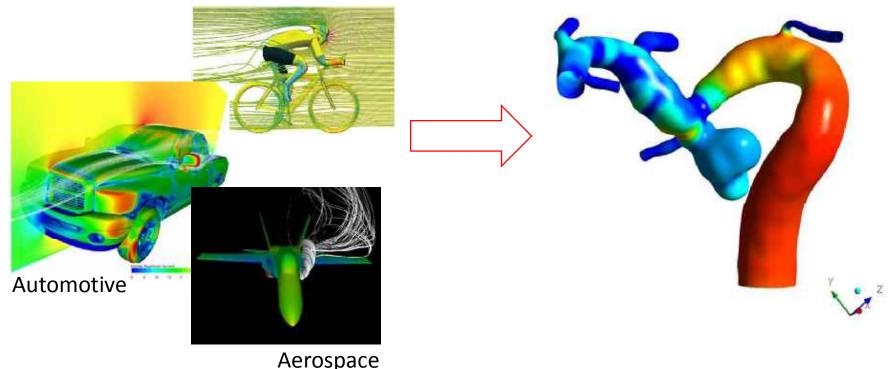


Click Here for Video

@neurIST technology: CFD



- Detailed in-vivo measurements of relevant flow variables in regions affected are currently impossible
- Motivated by its success in other disciplines scientists started using CFD to predict blood flows in IAs

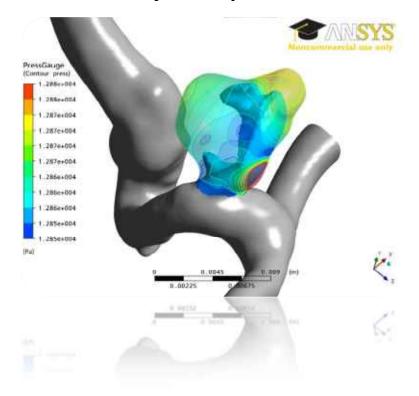


Sports Engineering

@neurlST technology: haemodynamic predictions



inflow jet and pressure



Wall Shear Transport 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 4, 100-001 1, 100-001

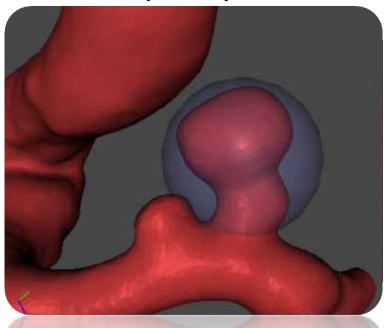
wall shear stress

@neurlST technology:



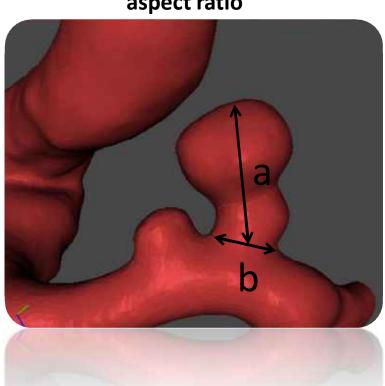
shape measurements

- non-sphericity-index (NSI): quantifies difference between aneurysm shape and a perfect circumscribed sphere
- Aspect ratio: ratio between aneurysm depth and neck max width. It has been correlated with aneurysm rupture [1]



non-sphericity-index

(1) Raghavan et al J Neurosurg 2005



aspect ratio

@neurIST technology:



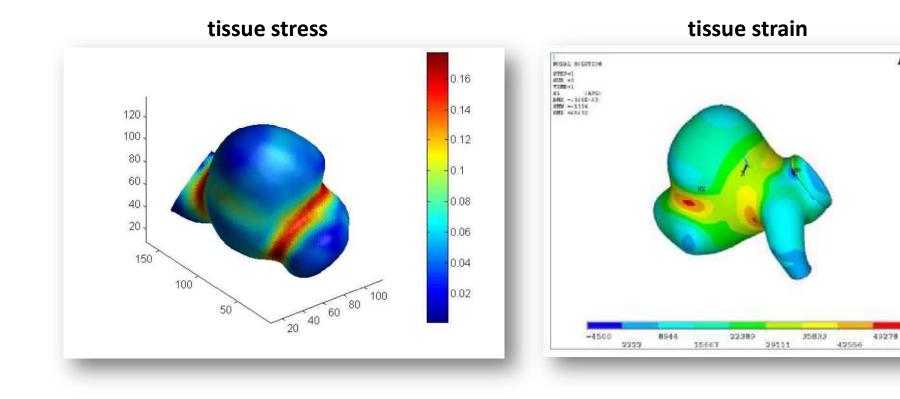
ΛN

195. 1 1411

56000

stress/strain predictions

it is likely that the event of rupture occurs when the tissue stress or strain exceeds some sustainable level





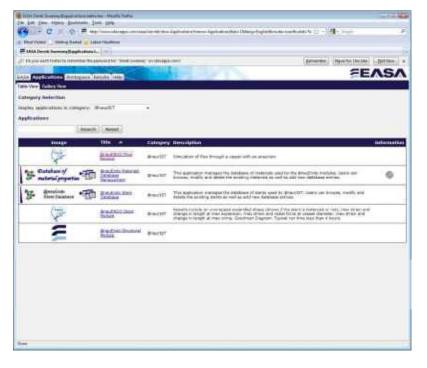
Live Demo

Unstented Case

Click Above for Demo

Analysis computation IDAC EASA web-based computing power

@neuFuse files can be uploaded on the web to run analyses using web-based computing power (IDAC EASA)



user interface

file uploading

Els Edit Jools View Help		
2 2 2 2 2 1 1 1 1 1 1 1 1 2 1 2 1 2 1 2		
D Parameters D Henuits Processor	I	
	Submit Job	
	Storma top	
Run Details	A DISTANCE DE LA DISTANCE	×.
Description	Case 1 Transient	
Input Selection		
Preprocess Crity		
C Depiny Stant 21 Gneutuse Input		
Solve using Amazon EC2		
and share a state of the state of the	STRATE STOLEN	
	e spata Do	
Vessal and Start Injuits		
VTIC Vessel Geometry	cytinder-geom tit 🛄	
VBC Nack Gaometry	neck-geom ida 🛄	
Problem Description File	apd-cyknoler.xml	
Additional Options		
C Model Elastic Vessel Behaviour		
Implanted Stent in Idealized Viessal		
		-0



Analysis computation IDAC EASA web-based computing power

Analysis status can be monitored and results (e.g. tabulated indices, WSS plots) accessed once analyses are completed

Bild-ben lines Brank made Installand In fat you opper histories live pre-14----FEASA NAMES FOR PARTY towing coulds up to rot. data and [mostify] [monot.] Distanting Place Places best 2 Beach P 18 NOV 1T TTUE Martal Alexan Interaction of Paris Name Hutst Hugh Countries of y 144 18.42110108.0 Disartin Play Holds Lawyeak 11 447 12 22 23 Hertis Haut and (Provident) Stread Will Place Market Committee of Contribution, raily 17 her 12 18-6 Shaikiai Marini 18 497 107 18,22 19 496 10 10 10 10 Marile Marial STRAIGHTO NEW WALLS nextNOC films Metals 17 Mar 18 July Annul Will Have Health Cartoniamo 27 May 18 20164 Statut Number Hutsi Hurara Indebits New Yorks 17 Per 18 alleh of Net 12 1818 Streamport Place Incide banag. 84 Mar 12 12-44 Statist Name Hutte Huighs Pre-Chill Film Harbor Concession of 17 Nov 18, 17, 17 Harris Mulate Bislando Nes Nadala La're-Article IN MALLER DATE Analysis from Herbits 5. Pair 10 14 17 Harris Rulpho Harris Rulpho Orecleted 27 140 23 25 34 Strength (201) Honey Openand Anjan 12

analysis status

results post-processing

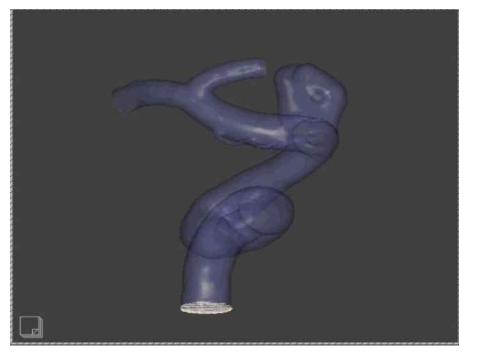
Conception of the second	Conception of the second	and have been been been about the				10000
					- 14 - mar	
We have been equipped where we can find a support Can characterize the second of the second	We have been equippedual desc. Conclusion	The land defend hered as Lon	(Inclusion)			
Quantitative: over cardiac syste: max the function of the second of t	Quantitative over cardiac cycle: mare the four overall of second active and the overall of second active overall of the seco					
Quantitative: over cardiac syste: max the function of the second of t	Quantitative over cardiac cycle: mare the four overall of second active and the overall of second active overall of the seco	Tanillan Cunla				
We from surged we show yet 1.4000-01 Set of the surged we show yet 1.4000-01	We from screed of reserved 1.4446-01 Set of from screed of reserved 1.4466-01 Set of reserved 1.4466-01 Set of reserved 1.4466-01 Set of reserved 1.4466-01 Set of reserved of reserved 1.4466-01 Set of reserved of reserved 1.4466-01 Set of reserved of reserved of reserved 1.4466-01 Set of reserved of reserved of reserved 1.4466-01 Set of reserved of reserved of reserved of reserved 1.4466-01 Set of reserved reserved reserved 1.4466-01 Set of reserved reserved reserved 1.4466-01 </td <td>cardiac cycle</td> <td></td> <td></td> <td></td> <td></td>	cardiac cycle				
Internet forms diverged with entropy 1.119-12 See of firms weighted with Sec Networks 1.028-021 (101-02) The set of firms weighted with Sec Networks 1.028-021 (101-02) The set of firms weighted with Sec Networks 1.028-021 (101-02) The set of firms weighted with Sec Networks 1.028-021 (101-02) The set of firms weighted with Sec Networks 1.028-021 (101-02) The set of firms weighted with Sec Networks 1.028-021 (101-02) The set of firms weighted with Sec Networks 1.028-021 (101-02)	Internet of them served 10 (1910) Inter of them served of the Served of the Served 10 (2010) Inter of them served of the Served of the Served 10 (2010) Inter of the Served of the Served of the Served 10 (2010) Inter of the Served of the Served of the Served 10 (2010) Inter of the Served of the Served of the Served of the Served 10 (2010) Inter of the Served o	Quantitative over cardiac s	ndes -			
Inter storing 1 MB (about 5 of the 10 (MB	mean streaming at this laws. As fac. 1,0000.001 (0,000.0000) mean streaming at this laws. As fac. 1,0000.001 (0,000.0000) mean streaming at this laws. This laws. As fac. 1,0000.001 (0,000.0000) mean streaming at this laws. This laws. As fac. 1,0000.001 (0,000.0000) mean streaming at this laws. This laws	The Trite Averaged No. 1 Anterport	1.5.4444-70			
Inset of the ansatzed PAG (and (and (and (and (and (and (and (and	Inset of the sense sense of Million 1.11 % 1.90 million 1.21 % Sense of the sense sense 1.90 million 1.11 % Parameter Sense sense 1.90 million 1.15 % Parameter Sense senses	service and home, since agent their re-service	er [3:419e-10			
The right 1.00 Description of theorems must 1.00 1.00 1.00 2.00 1.00	The right 1.20 Description of Homosys (H) 1.20 1.20 1.20 2.20 2.20 Description of Homosys (H) 1.20 2.20 2.20 Description of Homosys (H) 1.20	man if then managed with balan 2.4 f	 10.008xx81103.% 			
International ISI I. Silve VI. I. Silve VI. Development of Management of Second Platters I. Silve VI. Provide a consequence of Second Platters I. Silve VI. Second Platters of Second Platters I. Silve VI	Instantion Instantion Development Instantion <td>may of time availaged WM above 1.81</td> <td>ta (1.904-05.) at 8.%</td> <td></td> <td></td> <td></td>	may of time availaged WM above 1.81	ta (1.904-05.) at 8.%			
answer of Resident 101 2.0000-02112.7%) Quarterization of Standard Statution Rev of A submittance 8.0000-021 New of A submitance 8.0000-021	anew of Revealed 101 2.44400.021.0.7.%) StructureTransfer 4.5.4460.021.0.7.%) StructureTransfer 5.7500-01 New of a the Animorphic Structure 5.7500-01 New of a the An	Page 1129	1.00			
Automitation at Steady Status The Vet 2 - Sense 1 Status Automit of a maximum Status Status Status Status Status Status Status Status Status Status Statu	Automitation at Stoudy State The Vid 2 memory at State The Vid 2 memory at State State The Vid 2 memory at State State State State State State State State State State State	Incomed of Watermark 200	10.205e W1.1.718e W1.1.488e H1			
Max Vel + Jameson E. 700-11 mass avgraph of the maximum E. 800-11 Souther of exclusion is maximum E. 800-11 mass fragment of the distribution E. 200-14 mass fragment of the distribution E. 200-16	Bits Vel + Jamespare E. Film-11 mann averaged (off a maximum) E. Miller 12 socker of not basis of a maximum E. Miller 13 mann averaged (off a maximum) E. Miller 14 mann averaged (off a maximum) E. Miller 14 mann averaged (off a maximum) E. Miller 14 mann averaged maximum) E. Miller 14 maximum film averaged maximum) E. Miller 14 maximum film averaged maximum) E. Aller 14 maximum film averaged maximum) E. Aller 14 maximum film averaged maximum) E. Aller 14 maximum averaged maveraged maximum) E. Aller 14	itms of Revised 191	2.846a-0718.7%)			
They Vel + Alementer E. 700-11 seen averaged ref in the second E. 800-11 seen averaged ref in the second E. 800-11 second of average ref in the second E. 800-11 second of average ref in the second E. 800-11 second of average ref in the second E. 800-11 second of average ref in the second E. 800-11 second of average ref in the second E. 800-11 second of average ref in the second E. 800-11 second of average ref in the second E. 800-11 second of average ref in the second E. 800-11 second of average ref in the second E. 800-11 second of average ref in the second E. 800-12 second of average ref in the second E. 800-12 second of average ref in the second E. 1800-12 second of average ref in the second E. 1800-12 second of average ref in the second E. 1800-12 second of average ref in the second E. 1800-12 second of average ref in the second E. 1800-12 second of average ref in the second E. 1800-12 second of average ref in the second E. 1800	They Vel + Journeyse E. 700-01 series averaged role or environme E. 800-01 series averaged role or environme E. 200-01 series averaged role or environme E. 200-01 <td< td=""><td></td><td>N and a state of the state of t</td><td></td><td></td><td></td></td<>		N and a state of the state of t			
Description 2 Ambody	Description Control Control Application Contro Control <td>Quantitative at Steady Stat</td> <td></td> <td></td> <td></td> <td></td>	Quantitative at Steady Stat				
Section 2 and Section 2 and Section 2 E Section 2 and Section 2 and Section 2 E Section 2 and Section 2 and Section 2 E Section 2 and Section 2 and Section 2 E Section 2 and Section 2 and Section 2 E Section 2 and Section 2 and Section 2 E Section 2 and Section 2 and Section 2 E Section 2 and Section 2 and Section 2 E Section 2 and Section 2 and Section 2 E Section 2 and Section 2 and Section 2 E	Section of sections is a section of the image o	Part Vel in James and	1.70+1			
The endargene is table Excluse E1 MAA, Barrish andregene is wall Excluse E1 MAA, Barrish andregene is wall Excluse E1 Strate E1 Excluse E1	Term with the extrangement ended Extra end MAA, Name Train with equipment drived Extra ender MAA, Name Train with equipment drived Extra ender MAA, Name Train with equipment drived Extra ender Maximum This with equipment drived Extra ender Maximum This with equipment drived Extra ender Maximum This with ender Extra ender	man womant of it emproved	1.00 m Dt			
Steady Back (Stargending) S. 1976-10. Steady Back (Stargending) S. 1976-10. <td>Andre Sterner Maxweigen die neue 3. 1200-13. Sentemen Kinste Verwahren die was 2.1200-13. Sentemen Kinste Verwahren die Witz 1.1200-13. Sentemen Kinste Verwahren die Witz 1.1200-13.</td> <td>includer of stationed in pressioners.</td> <td>1</td> <td></td> <td></td> <td></td>	Andre Sterner Maxweigen die neue 3. 1200-13. Sentemen Kinste Verwahren die was 2.1200-13. Sentemen Kinste Verwahren die Witz 1.1200-13.	includer of stationed in pressioners.	1			
restartion flux the sensity of state 1 200-04 and the mail of a mark with the mail 1 200-04 mark at the mail of a mark with the mail 1 200-04 marked advector of the sensitivity of a 1 200-04 marked advector of the sensitivity of o	restance No the encourse divised (L 2016-0- anergy No 114 analysis and sectors of the Color of	men wel alle and unversion of bank	trave to			
restartion flux the sensity of state 1 200-04 and the mail of a mark with the mail 1 200-04 mark at the mail of a mark with the mail 1 200-04 marked advector of the sensitivity of a 1 200-04 marked advector of the sensitivity of o	restance No the encourse divised (L 2016-0- anergy No 114 analysis and sectors of the Color of	man far you measure a real	1.007e-11			
servery line understand served E. Arthus 191 servery line understand A. Arthus 191 servery line understand C. J. Servery 191 servery line understand S. J. Servery 191 servery line understand T. J. Servery 191 servery line understand S. Servery 191 servery line understand S. Servery 191 servery 191 S. Servery 191 <td>servery from the served E. Arches 10 servery from the served in the served E. Arches 10 servery from the served in the served</td> <td></td> <td>3,004-04</td> <td></td> <td></td> <td></td>	servery from the served E. Arches 10 servery from the served in the served E. Arches 10 servery from the served in the served		3,004-04			
Indua Researchin 4.843.49 (87.2 m) Unduark Researchin 4.841.99 (87.2 m) Unduark Researchin 4.841.99 (87.2 m) Unduark Oncomparison on unity remain will be a comparison of unity remain will be a comparison	Index and acception. 4.4414-09.04.07.09.0 Lobalization desequences. 6.5000-010.0 Model and Acception. 6.5000-010.0					
contract desegnation 4 Artitute 10 they linearized are not encryment and the contract of the contr	contract sequences 4 wither B1 they investigation of encryptome and C. (2000) CPU (2.000) CPU contract of encryptome and CPU (2.000) CPU					
The Revelues to encryption and C. Rev 19 subtract dimensionant the C. Rev 10, L. Stere 0, L. March enc di decemb Rev 0.0444 R. State 01, D. State 01, D. State R. State 01, D. State 01, D. State R. State 01, D. State 01, D. State R. State 01, D. S	tes Development te en prome est C. Miseria C. Jane D.					
Solitor of surgement the CLEMENT ALSO BED ALSO B	Authors of any specific time (CL2006-01, L2706-01, L2400-01) Anna of Automatic France Datage (CL2006-01, L2206) Mark of the Automatic France Datage (CL2006-01)	the second se	1. Milevilia			
Head of selected in New Galage 21,2056-901 (52-95). This left an energy solution with 21,21,216-913	Head of selected in New Galage 2, T2006-WE (10.5 %). This left as determined with (1.2 %).					
This will be described and A Exchericit	The UT of environment of LTIDE-U	the strength bit, by its data and the literature states in the	the start is the start of the s			
AN			and a stand of the			
	Living Pre-	map of anomal WED Taxonic	LUB-WIELS	AN		
		Velocity				
Velodity	Velocity					
Back Velocity	Basic Venezart	0.2				
Back Velocity	(hash Veneral)					
Bank Velentyi a J	Rent Venethal 0.3	0.2				
Back Velocity	Bank Volkettyl a 3					
Bank Velentyi a J	Rank Velicetul B 2					



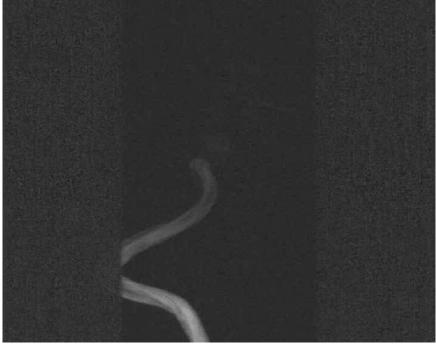




it is likely that the event of rupture occurs when the tissue stress or strain exceeds some sustainable level



Virtual Angio



Real Angio

Click Here for Video

Click Here for Video

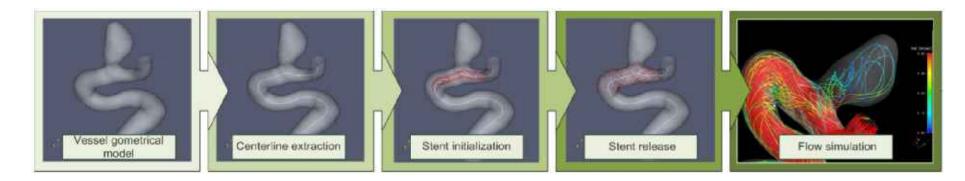


Stented Case

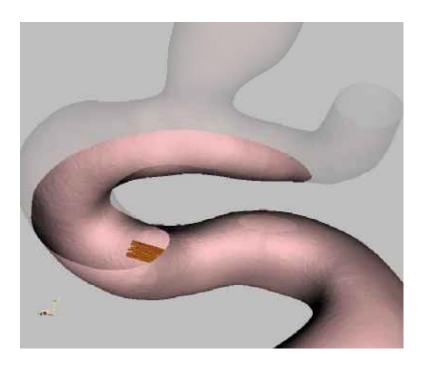
Click Above for Demo



@neurEndo Virtual Endovascular Treatment

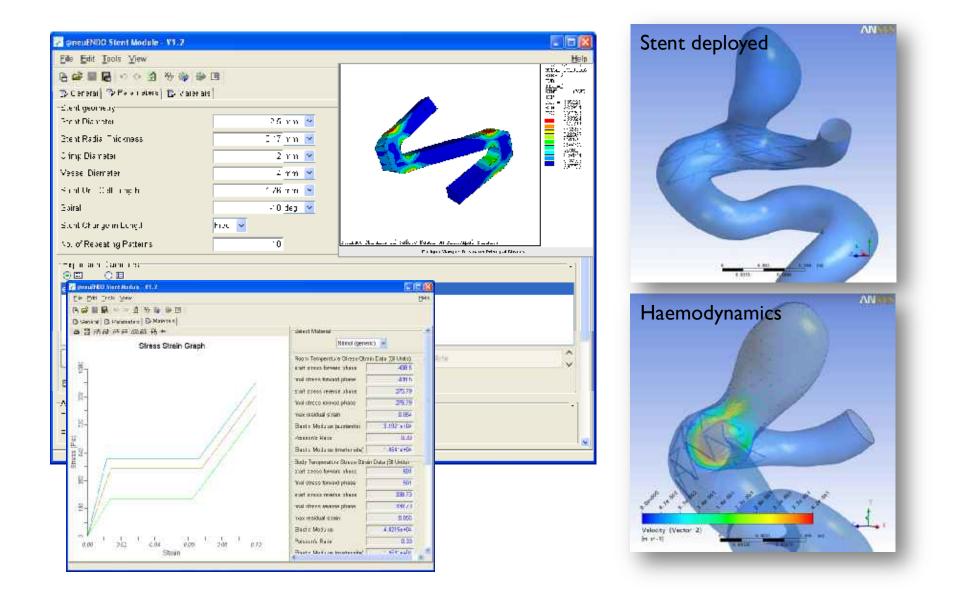


- The stent is represented by a deformable model expanding into the vascular lumen
- The stent deformation is constrained with information on the stent design (strut length, angle between struts)
- Time consumption: approximately 1 minute





@neurEndo Virtual Endovascular Treatment





Physical Characterisation of Cerebral Aneurysms and Identification of Factors Suggestive of Imminent Rupture

TM Murphy^{1,3}, A Marzo², DR Rawluk¹, C Bolger^{1,4}

1 Department of Neurosurgery, Beaumont Hospital, Dublin.

2 Department of Cardiovascular Engineering, Royal Hallamshire Hospital, Sheffield

3 Department of Vascular Research Engineering, University College Dublin

4 Department of Neurosciences, Royal College of Surgeons of Ireland, Dublin



Updated ISUIA (2003)

	< 7	< 7	7-12	13-24	≥25
	Group 1	Group 2			
Cavernous carotid	0	0	0	3%	6.4%
AC/MC/IC	0	1.5%	2.6%	14.5%	40%
Post-P comm	2.5%	3.4%	14.5%	18.4 %	50%



Materials and methods

- Retrospective pilot study investigating role of haemodynamic indices in subarachnoid haemorrhage
- 10 patients from Beaumont Hospital recruited
- Ethical approval
- 3D rotational acquisitions (3DRA) images were processed with @neuFuse

Case	Age	Urgency?	Location	Size
1	59	Elective	Basilar	4
2	59	SAH	R P Comm	3
3	53	SAH	R P Comm	2
4	35	Elective	R P Comm	3
5	42	SAH	Basilar	10
6	35	SAH	R ICA	3
7	66	SAH	L P Comm	10
8	67	SAH	L P Comm	6
9	57	SAH	R P Comm	10
10	60	Elective	L P Comm	7

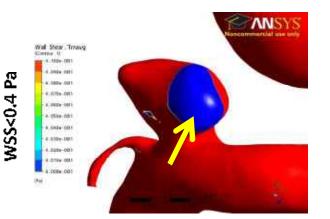


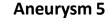
Haemodynamic Results

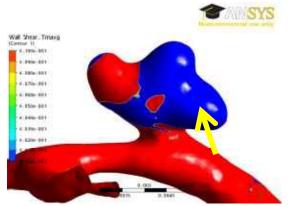
Infra-physiological time-ave Wall Shear Stress (<0.4 Pa)

Case Number	Age	Ruptured?	Location	Size	Area WSS<0.4Pa (mm²)	% WSS<0.4Pa
1	59	Elective	Basilar	4	0	0
2	59	SAH	R P Comm	3	7.5	11.4
3	53	SAH	R P Comm	2	0	0
4	35	Elective	R P Comm	3	0	0
5	42	SAH	Basilar	10	76.6	59.4
6	35	SAH	R ICA	3	0	0
7	66	SAH	L P Comm	10	16.9	7.4
8	67	SAH	L P Comm	6	4.7	5.6
9	57	SAH	R P Comm	10	0	0
10	60	Elective	L P Comm	7	0	0

Aneurysm 2

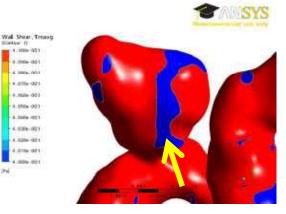






Aneurysm 7

minutes, 11



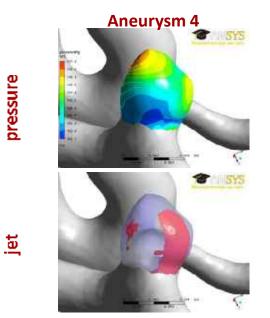
Haemodynamic Results

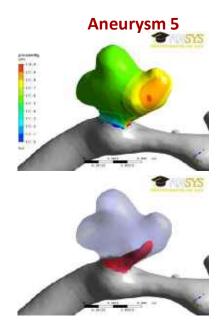


Jet impingement at peak systole

Case Number	Age	Ruptured/Elective	Location
1	59	Elective	Basilar
2	59	SAH	R P Comm
3	53	SAH	R P Comm
4	35	Elective	R P Comm
5	42	SAH	Basilar
6	35	SAH	R ICA
7	66	SAH	L P Comm
8	67	SAH	L P Comm
9	57	SAH	R P Comm
10	60	Elective	L P Comm

Size (mm)	Maximum Pressure (mmHg)	Area Pressure Elevated (%)
4	100.8	0.2
3	110.5	0.6
2	114.3	3.2
3	118	16.5
10	119.5	0.2
3	109	8
10	103	2.6
6	106	6.4
10	141	3
7	110.5	52



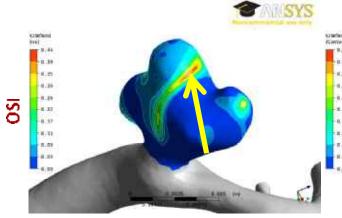


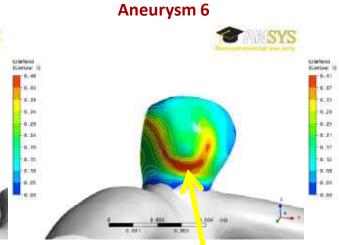
Haemodynamic Results

Oscillatory Shear Index

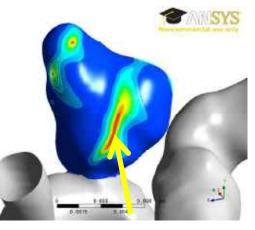
Case Number	Age	Ruptured/Elective	Location	Size	Maximum OSI	Area Elevated OSI (%)
1	59	Elective	Basilar	4	0.32	0.7
2	59	SAH	R P Comm	3	0.47	7.7
3	53	SAH	R P Comm	2	0.38	4.5
4	35	Elective	R P Comm	3	0.28	0.9
5	42	SAH	Basilar	10	0.44	4
6	35	SAH	R ICA	3	0.48	24.1
7	66	SAH	L P Comm	10	0.41	3.4
8	67	SAH	L P Comm	6	0.42	1.2
9	57	SAH	R P Comm	10	0.44	3.0
10	60	Elective	L P Comm	7	0.38	8.9







Aneurysm 7





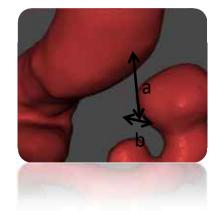


Morphological Results

Shape indices automatically extracted from @neuFuse

Case Number	Age	Ruptured/Elective	Location	Size	Aspect Ratio	Non-sphericity index	Size ratio
1	59	Elective	Basilar	4	0.92	0.09	1.5
2	59	SAH	R P Comm	3	1.38	0.2	1.71
3	53	SAH	R P Comm	2	0.81	0.12	0.86
4	35	Elective	R P Comm	3	0.92	0.09	1.63
5	42	SAH	Basilar	10	2.09	0.29	2.36
6	35	SAH	R ICA	3	1.27	0.15	1.25
7	66	SAH	L P Comm	10	2.59	0.26	2.49
8	67	SAH	L P Comm	6	1.83	0.25	1.81
9	57	SAH	R P Comm	10	1.88	0.29	3.09
10	60	Elective	L P Comm	7	0.87	0.21	0.83

AN



Aneurysm 5

SYS SYS

Aneurysm 1

Aneurysm 6

Aneurysm 2

Aneurysm 7

Aneurysm 3



Aneurysm 8

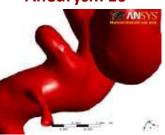


Aneurysm 9

Aneurysm 4

SY5

Aneurysm 10



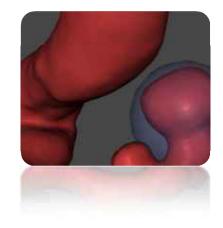


Morphological Results

Shape indices automatically extracted from @neuFuse

Case Number	Age	Ruptured/Elective	Location	Size	Aspect Ratio	Non-sphericity index	Size ratio
1	59	Elective	Basilar	4	0.92	0.09	1.5
2	59	SAH	R P Comm	3	1.38	0.2	1.71
3	53	SAH	R P Comm	2	0.81	0.12	0.86
4	35	Elective	R P Comm	3	0.92	0.09	1.63
5	42	SAH	Basilar	10	2.09	0.29	2.36
6	35	SAH	R ICA	3	1.27	0.15	1.25
7	66	SAH	L P Comm	10	2.59	0.26	2.49
8	67	SAH	L P Comm	6	1.83	0.25	1.81
9	57	SAH	R P Comm	10	1.88	0.29	3.09
10	60	Elective	L P Comm	7	0.87	0.21	0.83

AN



Aneurysm 1

Aneurysm 2

Aneurysm 3



Aneurysm 8



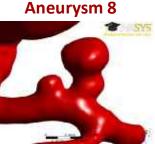
Aneurysm 4

Aneurysm 5 * SYS

Aneurysm 6

Aneurysm 7







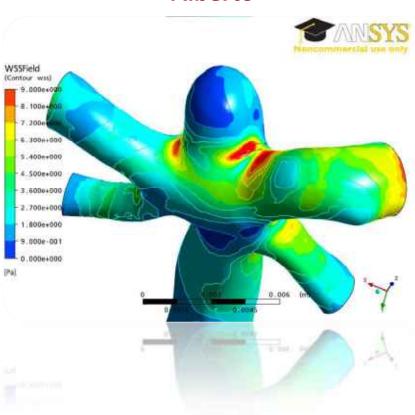




Qualitative comparison

case 1 – wall shear stress

Martin MSYS WS5Field (Contour was) 9.000+900 8.100e+000 7.200e+0 6.300++000 5.400e+000 4.500e+000 3.6000+000 2,700e+000 1.800e+000 9.000e-001 0.000e+000 Pal. 0.005



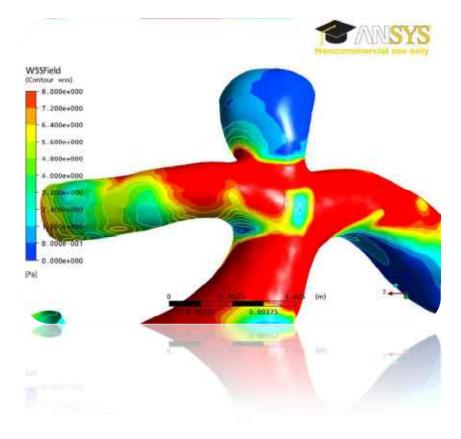
Alberto

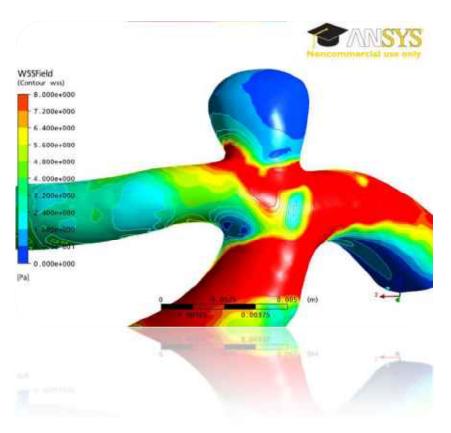


Qualitative comparison

case 8 – wall shear stress

Martin





Alberto

Results Summary



 Accepted "wisdom" 	Predicted the SAH patients?
 Size matters (7mm) 	3/7
 Proposed indices 	
 Aspect ratio (1.6) 	5/7
 Size ratio (3) 	1/7
WSS	4/7
 Oscillatory shear index (0.40) 	6/7
 Non-sphericity index (0.183) 	6/7

- The software is easy to use by clinicians
- Results were interchangeable with Dr Marzo's within 5 cases.
- 45 minutes clinician time + 2-3 hours computation



Conclusions

- Size is not the best predictor of aneurysm's rupture potential
- Haemodynamic and shape indices may have greater influence on rupture potential
- Strongest correlations found for Oscillatory Shear Index and Non-sphericity index

Dissemination



The software has been exposed and used by clinicians at several venues with positive feedback

□ Feedback was collected and used to improve the software

Location: Boston, USA Conference: WFNS 2009 Exposure: Workshop Participants: 38 neurosurgeons Feedback: Overall impression positive, audience showed great interest @neurIST

Location: Lisbon, Portugal Conference: ESMINT 2008 Exposure: Workshop Participants: 36 neuroradiologists, neurosurgeons, engineers Feedback: Very positive

Location: Santiago, Chile Conference: SILK-Workshop 2009 Exposure: Workshop Participants: 22 Endovascular Neuroradiologists Feedback: Very positive, GUI needs improvement



Published in Computational Intelligence and Neuroscience 2009 Location: Bertinoro, Italy Conference: ICCB 2009 Exposure: Workshop Participants: 13 biomedical engineers Feedback: Engineering community showed great interest and positive feedback

Location: Nagoya, Japan Conference: ICCVS 2009 Exposure: Presentation Participants: 50+ neurosurgeons Feedback: Audience showed great enthusiasm

Location: Barcelona, Spain Conference: ESMINT 2009 Exposure: Workshop Participants: 104 neuroradiologists, epidemiologists, engineers, neurosurgeons Feedback: Positive



What next?

- We can offer tools and services to support the following activities:
 - Research into cerebral aneurysms
 - Research into other vascular diseases
 - Patient specific CFD study*
- Typical cost for a 100 Case Research Project would be €10,000. This includes
 - Initial training in use of software and interpretation of results
 - Tailoring of report and output data
 - Ongoing support and training
 - Use of @neuFuse and @neuEndo software
- Typical cost for a single patient CFD study would be € 400. This includes
 - Transient CFD study
 - Interactive discussion with clinician on results
 - Presentation of results in summary report
- Open Forum
 - \circ Feedback
 - o Interest in further collaboration
 - Can we identify a funded research project?





e II

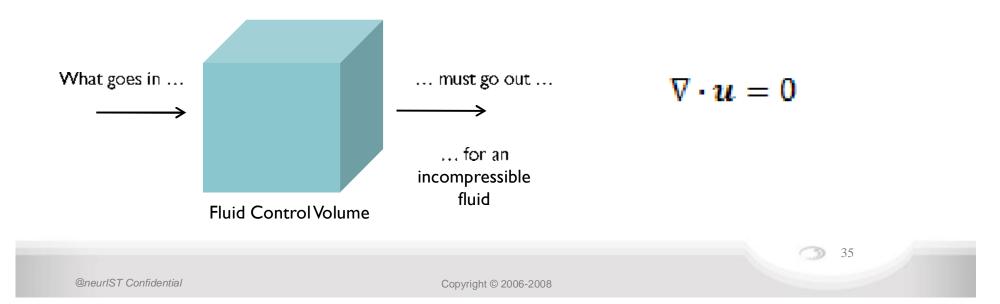
- CFD is the science of predicting fluid flow, heat and mass transfer and it's based on the **physical principles** that govern any fluid flow:
 - Conservation of Mass
 - Conservation of Momentum (Newton's Second Law)
 - Conservation of Energy (First Law of Thermodynamics)





neu

- CFD is the science of predicting fluid flow, heat and mass transfer and it's based. on the physical principles that govern any fluid flow:
 - **Conservation of Mass**
 - Conservation of Momentum (Newton's Second Law)
 - Conservation of Energy (First Law of Thermodynamics)

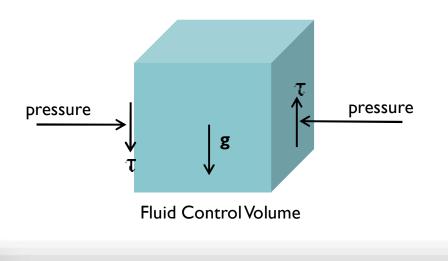






neu

- CFD is the science of predicting fluid flow, heat and mass transfer and it's based. on the physical principles that govern any fluid flow:
 - Conservation of Mass
 - Conservation of Momentum (Newton's Second Law)
 - Conservation of Energy (First Law of Thermodynamics)



$$\rho\left(\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u} \cdot \nabla \boldsymbol{u}\right) = -\nabla \boldsymbol{p} + \nabla \cdot \boldsymbol{T} + \boldsymbol{f}$$

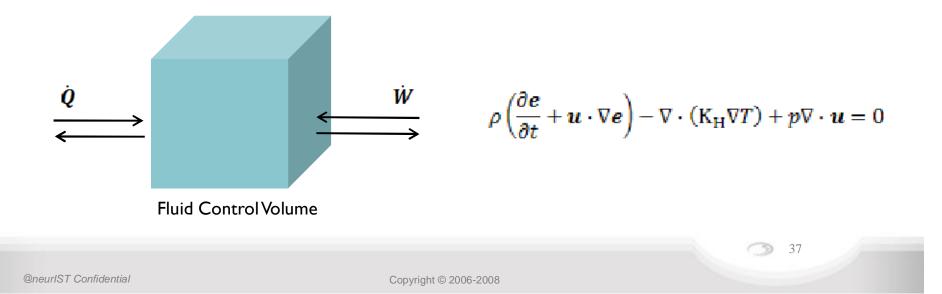
36 5





neu

- CFD is the science of predicting fluid flow, heat and mass transfer and it's based. on the physical principles that govern any fluid flow:
 - Conservation of Mass
 - Conservation of Momentum (Newton's Second Law)
 - **Conservation of Energy (First Law of Thermodynamics)**







APPENDIX Computational Fluid Dynamics -Navier-Stokes Equations

$$\nabla \cdot \boldsymbol{u} = 0$$
$$\rho \left(\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u} \cdot \nabla \boldsymbol{u} \right) = -\nabla p + \nabla \cdot \boldsymbol{T} + \boldsymbol{f}$$

$$\rho\left(\frac{\partial \boldsymbol{e}}{\partial t} + \boldsymbol{u} \cdot \nabla \boldsymbol{e}\right) - \nabla \cdot (\mathbf{K}_{\mathrm{H}} \nabla T) + \boldsymbol{p} \nabla \cdot \boldsymbol{u} = \boldsymbol{0}$$

Analytical or closed solution currently impossible for complex physical problems

Designated as Millenium Problem by Clay Mathematics Institute in Cambridge, MA, USA. Solution worth 1M \$





APPENDIX Computational Fluid Dynamics – The engineering trick

neu

pressure waveform

