ZooMS: a non invasive analysis of global and metameric movement of the lumbar spine

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Aim. **The assessment of spine mobility is an important parameter to define its functionality. In the last decades a lot of research has been carried out mainly through radiographic investigations; non invasive methods demonstrated not to be sufficiently accurate, not to allow free movement, not to provide metameric assessment and suitable for everyday clinical practice. The aim of this study is the development of a new experimental non invasive protocol, called Zoom on mobility of the spine (ZooMS) to assess the mobility of lumbar spine, from the 11th thoracic to the sacrum bone and the pelvis, with the possibility of identifying the metameric contribution of each rotation around all the axes correlated to the global movement.**

Methods. **We developed a dedicated non invasive methodology based on optoelectronic techniques for 3D target recording to be applied to the functional evaluation of the mobility of the lumbar spine in young healthy males. Ten subjects participated in the method validation, performing free rotations (flexion/extension, lateral bending and axial rotation) from standing to the maximum excursion and back.**

Results. **The comparison of the range of motion (RoM) with those presented in literature was satisfactory, although some differences were shown (above all in axial rotation, which however gives the minor contribution to the mobility of the lumbar spine). The validation of the protocol was successful in terms of intraoperator, interoperator and circadian remarking, the 3 factors eventually affecting its repeatability.**

Conclusion. **The RoM of the whole lumbar spine and of each functional unit, together with the pattern of movement may so represent an innovative and important aspect in clinical applications.**

KEY WORDS: **Spine - Quantitative functional analysis - Back pain - Posture - Metameric - Global mobility.**

This manuscript is based on the research "Nuova strategia riabilitativa funzionale per le algie di origine lombare con elevata disabilità lavorativa: studio randomizzato controllato per la verifica di efficacia clinica, di appropriatezza in termini di costo-beneficio con lo sviluppo di nuovi ulteriori indicatori di esito e di controllo di qualità" supported by a grant of Ministero of Health - Italy

Submitted for publication September 28, 2004.
Accepted March 3, 2005.

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The clinical assessment of spine mobility is actually a basic parameter to define the functionality of the spine and it probably gives the main contribution, together with described pain, to support the physician in drawing diagnosis, treatment definition and follow-up.[1-5] This last issue, *i.e.* the follow-up of a rehabilitation treatment, requires also the possibility to frequently repeat the evaluation in order to have a better, maximally customized, therapeutic approach. This excludes the commonly used diagnostic method, *i.e.* radiology.[6-10]

The non invasive alternative, using inclinometers,[11-13] provided not so accurate results: this is a low technological device requiring an inexpensive instrumentation that showed good results only in studies extended to the whole lumbar spine, from L1 to L5, without a metameric evaluation. Its application is also intrusive for the movement execution.

Other researchers preferred the use of a computerized three-axial potentiometric system [14] to record the lumbar spine movements in the 3 main directions. This is important because it can also extend the assessment, not limiting it to the main axis of rotation, considering the fact that the spine is a cinematic chain and every rotation around one axis implies also rotations around the other axes. The innovation introduced by these systems at that time was the possibility to evaluate movement of the spine along all the 3 axes of rotation even if by using an intrusive device with respect to the natural movement. Furthermore the experimental setup was a little bit complex, so not suitable for a daily use in clinical practice.

The last category of instrumentation used by researchers includes all the opto-electronic devices for motion analysis (MA), where the body movement is measured by the recording of the position of a set of active or passive markers (these do not really interfere with the movement) and are attached to the subject.[15-19]

The most important feature of these systems is doubtlessly the non invasive analysis, even if there is a loss of precision during the measurement process, due to the indirect assessment of the vertebrae position and motion, *i.e.* the external marking of the bone of the spine.

The spine mobility considered in terms of both quantity and quality should be also taken into account; while the quantity is described by range of motion (RoM),[7-9, 12, 14, 20] the qualitative MA is still to be defined and quantitatively evaluated. In the last decades a lot of research has been carried out mainly through radiographic investigations; non invasive methods demonstrated not to be sufficiently accurate, not to allow free movements, not to provide functional unit (FU) assessment, and not to permit routine everyday use. Therefore, from a scientific viewpoint, despite all these efforts no conclusive data on living subjects are available in literature neither for the metameric movements nor for the modification of the RoM due to age or pathology.

In general, the aim of this study is the development of a new experimental non invasive protocol, called zoom on mobility of the spine (ZooMS) to assess the mobility of lumbar spine, from the 11th thoracic to the sacrum bone and the pelvis, with the possibility of identifying the metameric contribution of each rotation around all the axes correlated to the global movement.

More in detail, we can identify 2 goals of the research, the first one related to the scientific aspect of assessment of the spine mobility also at each single metameric level and describing how the motion is performed, the second one focused on the clinical aspect of providing a quantitative contribution to the decision and follow-up of rehabilitative treatments.

This paper describes the method and the results of the validation in terms of both comparison with literature findings and evaluation of its repeatability.

Materials and methods

ZooMS is a dedicated system composing a specific protocol through a set of markers for data acquisition and a software suite for data processing dedicated to spine mobility analysis. ZooMS was implemented through an opto-electronic multicamera system for human MA (ELITE, BTS SpA., Milan, Italy) [2] in a 8 TV-cameras configuration; Figure 1 describes the laboratory setup.

The experimental protocol requires the positioning of 28 markers (plastic hemispheres covered by reflecting film, 6 mm in diameter): 3 onto each vertebra from the 11th thoracic (T11) to the sacrum bone (S1)—1 in correspondence to the spinous process and 2 geometrically on the left and right side onto the paravertebral points over the transverse processes—*i.e.* cranially on the paravertebral muscles 1 cm apart from the midline and equally distant from 2 spinous processes, for a total of 24 markers onto the vertebrae, and 4 on the pelvis bone (on the superior iliac crests and the superior iliac posterior spines). Figure 2 shows the positions of the markers on one test subject and the corresponding biomechanical model.

Markers were placed by clinician or skilled operator after training and experience in recognition of the position of spinous and transversal processes, by manual identification.

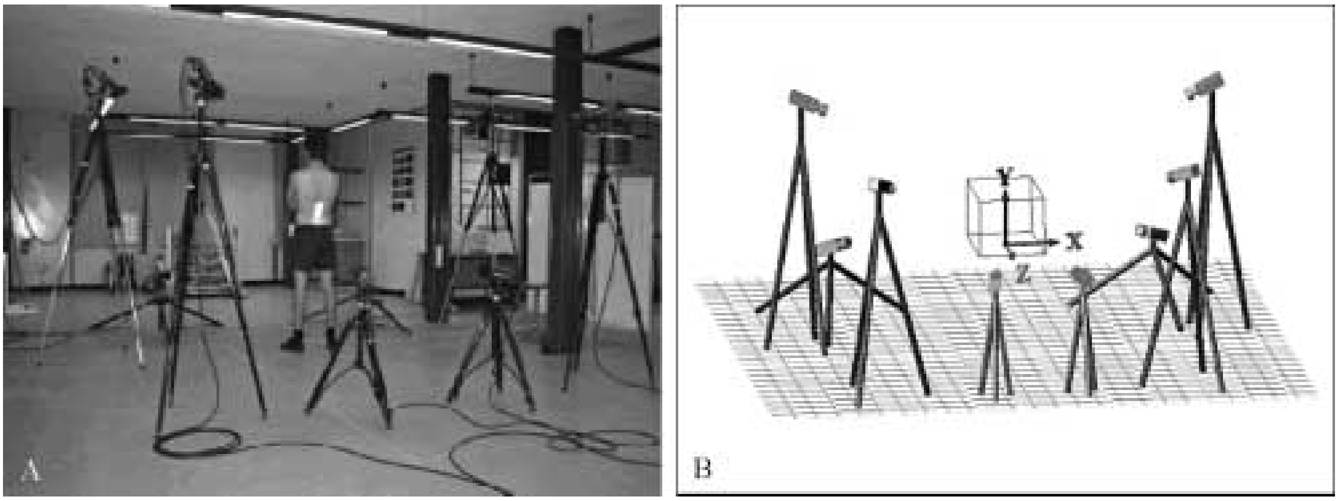

Figure 1A, B.—Laboratory setup for ZooMS analysis.

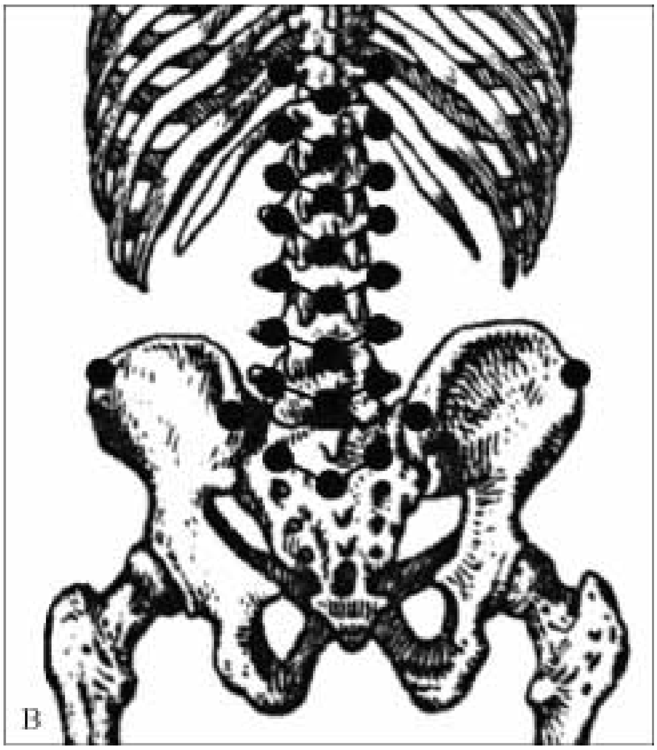

Figure 2.—The position of the markers (A) and the corresponding biomechanical model on the skeleton (B).

During the data acquisition protocol, the subject was asked to perform free movements in the sagittal, frontal and horizontal planes: flexion, extension, left and right lateral bending, left and right axial rotation from standing to the maximum excursion and back; every acquisition included the initial and final standing. Each movement was performed 3 times at a natural velocity chosen by the subject and with a continuous pattern, *i.e.* without a break at the end of the maximum joint movement.

TABLE I.—*Method validation with respect to the literature.*

	Combined flexion/extension				One side lateral bending				One side axial rotation			
	RoM		RA		RoM		RA		RoM		RA	
	WP	ZooMS	WP	ZooMS	WP	ZooMS	WP	ZooMS	WP	ZooMS	WP	ZooMS
T11-T12 FU	6-20	2-13	12	9	4-13	2-7	9	4	2-3	3-10	2	6
T12-L1 FU	6-20	10-25	12	14.5	5-10	2-7	8	4	2-3	4-12	2	6.5
L1-L2 FU	5-16	10-23	12	16	3-8	3-8	6	5	1-3	2-10	2	6
L2-L3 FU	8-18	11-23	14	21	3-10	2-9	6	6	1-3	3-10	2	5
L3-L4 FU	6-17	11-30	15	20.5	4-12	4-13	8	8	1-3	2-7	2	4.5
L4-L5 FU	9-21	15-28	16	22	3-9	6-16	6	10	1-3	2-8	2	4
L5-S1 FU	10-24	13-27	17	21.5	2-6	4-15	3	8	0-2	2-9	1	5
Sacro-iliac joint		10-30		18		3-17		10		2-8		4

FU: functional unit. RoM: range of motion. RA: representative angle. WP: White and Panjabi.

The 3D position of each marker was acquired at a sample rate of 100 Hz; the position and rotation of each vertebra was calculated from the 3 markers, referring to the same bone, through a specific model based on computation of Euler angles and identification of anatomical axes. From these information we obtained the RoM and MA of the lumbar spine and its FUs.

Ten healthy male subjects (age 27.5±2.1 year, height 175.5±4.4 cm, weight 72.3±10.2 kg), not suffering from previous lumbar pathologies, participated in this phase of the research with the main purpose of the validation of this new experimental protocol. This was necessary before its application in clinics and it also allowed developing a normaly data collection of healthy young people for further clinical comparison and evaluation.

The 3D data were filtered (low-pass Butterworth filter with adaptive frequency in general less than 5 Hz) and then processed by a specifically developed software implemented in MATLAB© (The MathWorks, Natick, USA) environment to compute the variables of interest: the absolute and relative rotations and the translations of each rigid body of the biomechanical model.

The development of a new protocol of analysis requires the validation before its definitive and clinical application. Firstly data obtained through ZooMS were evaluated and compared with literature findings. Then the verification of the repeatability of the results was also taken into account, singularly considering variations in the experimental tests of each parameter of the protocol: same observer different sessions, different observers, daily changes in the test conditions. Therefore to analyse the variability in marking the subject, the following tests were performed:

— intraoperator remarking: repositioning of the markers on the subject by the same operator in 2 separate sessions;

— interoperator remarking: repositioning of the markers on the subject by 2 different operators in the same experimental session;

— circadian remarking: to assess possible variability in the results due to the different hours in the day when the experimental session was carried out (this trial considers the daily variations in the spine length and curvature due to the effect of gravity). The purpose of this test was the evaluation of possible differences in the movements and correspondingly in the results between experimental sessions carried out in the morning or in the late afternoon after normal daily activities. In fact the spine modifies during the day under the effect of the gravity force.[22, 23]

So these trials aimed at confirming that the protocol could be performed at any time of the day. These tests were carried out with the remarking by the same skilled operator.

Recapitulating, the whole experimental design for the protocol validation was the following:

— morning: same operator, twice consecutively, then a second operator;

— evening: third evaluation by the first operator.

The considered variables in the analysis of the repeatability were the root mean square error (e_{rms}) and the correlation r^2 coefficient for the MA.

TABLE II.—*Intraoperator repeatability of motion analysis of the lumbar spine performed through ZooMS.*

	r_2		e_{rms}			r_2		e_{rms}	
	Mean	SD	Mean	SD		Mean	SD	Mean	SD
Flexion					*Extension*				
T11	0.9910	0.0072	5.0362	1.6487	T11	0.9163	0.0522	4.4187	1.4299
T12	0.9924	0.0065	4.7204	1.4676	T12	0.9149	0.0518	4.4798	1.5636
L1	0.9913	0.0071	5.0343	1.3255	L1	0.8855	0.0707	5.2342	1.1553
L2	0.9905	0.0086	4.4856	1.7713	L2	0.8933	0.0690	5.0112	1.4020
L3	0.9880	0.0080	4.5416	1.3453	L3	0.8916	0.0290	4.9865	1.4879
L4	0.9861	0.0114	4.0996	1.1308	L4	0.8650	0.0630	4.3511	1.0258
L5	0.9805	0.0130	4.4718	1.6483	L5	0.8429	0.1473	3.7260	2.1885
S1	0.9665	0.0265	4.7666	1.5535	S1	0.7137	0.1611	5.4906	3.5852
Pelvis	0.9831	0.0143	3.1902	1.5669	Pelvis	0.9070	0.0953	2.7792	0.9192
Right bending					*Left binding*				
T11	0.9649	0.0320	3.5563	1.1610	T11	0.9795	0.0084	3.2128	0.6496
T12	0.9588	0.0319	3.7999	1.5289	T12	0.9808	0.0069	2.8482	0.5251
L1	0.9568	0.0344	3.7707	1.1897	L1	0.9733	0.0158	2.8843	0.4687
L2	0.9492	0.0362	3.4059	0.6598	L2	0.9666	0.0196	2.6458	0.4883
L3	0.9455	0.0317	3.0750	1.1349	L3	0.9683	0.0154	2.4387	0.5554
L4	0.9199	0.0447	3.4198	1.3176	L4	0.9470	0.0282	2.9096	0.6260
L5	0.8308	0.1085	3.3158	0.7518	L5	0.8976	0.0641	2.6722	1.2486
S1	0.7012	0.1984	2.6887	1.1548	S1	0.7319	0.1549	2.5869	1.1710
Pelvis	0.9548	0.0339	1.5669	0.6553	Pelvis	0.9760	0.0136	1.6381	0.5829
Right rotation					*Left rotation*				
T11	0.9748	0.0190	4.8285	1.2914	T11	0.9696	0.0272	5.0862	1.7729
T12	0.9799	0.0129	4.5106	1.4546	T12	0.9773	0.0162	4.7789	1.2679
L1	0.9762	0.0217	5.8025	2.0569	L1	0.9804	0.0092	4.4970	0.6290
L2	0.9791	0.0161	5.5262	2.4073	L2	0.9802	0.0172	4.4650	1.6337
L3	0.9805	0.0123	5.4265	2.0195	L3	0.9869	0.0081	4.2683	1.1232
L4	0.9806	0.0122	5.1660	1.6296	L4	0.9870	0.0086	4.4595	0.9865
L5	0.9842	0.0111	4.7579	2.0078	L5	0.9863	0.0093	4.3641	1.2749
S1	0.9804	0.0136	5.0712	1.7842	S1	0.9851	0.0113	4.2530	1.1601
Pelvis	0.9838	0.0118	5.2110	2.0656	Pelvis	0.9873	0.0101	4.0259	1.2603

Results

Comparisons with literature findings

The comparison of the RoM with those presented in literature seems to be adequate. Table I shows the extremes with the representative angle (RA) for the RoM even if obtained with other methodologies not properly comparable *i.e.* the value were measured through passive movements on cadaver specimens.

Surface MA is affected by errors due to the marker positioning on the subject and to the unavoidable skin motion artefacts.

Furthermore, the movement and the muscular contractions during the experimental trials produce modification of the back morphology especially during the flexion-extension movements.

Repeatability analysis for intraoperator remarking

Tables II shows the results of the intraoperator repeatability.

Concerning the intraoperator remarking, the correlation described by the r^2 coefficients is really good (r^2 >0.96) in flexion and axial rotation movements. Lateral bending movements show r^2 >0.94, except for the sacrum bone S1 (worst case r^2=0.70±0.2 for rightward lateral bending), L5 bone (worst case r^2=0.83±0.11 for rightward lateral bending) and L4 rightward lateral bending (r^2= 0.92±0.04); the r^2 coefficients in the extension movements present quite low values at all levels, probably due to the big skin movement artefacts. Also e_{rms} is always limited to very few degrees often because of the non perfect synchronization in time of the movement phases.

TABLE III.—*Interoperator repeatability of motion analysis of the lumbar spine performed through ZooMS.*

	r_2		e_{rms}			r_2		e_{rms}	
	Mean	SD	Mean	SD		Mean	SD	Mean	SD
Flexion					*Extension*				
T11	0.9882	0.0066	5.4826	1.6079	T11	0.8865	0.0663	4.9504	1.7690
T12	0.9884	0.0071	5.6766	2.0301	T12	0.8810	0.0640	4.9510	1.4968
L1	0.9872	0.0074	5.9433	2.1333	L1	0.8933	0.0355	5.1502	1.3727
L2	0.9853	0.0102	5.2769	1.9372	L2	0.8689	0.1045	4.5615	1.6284
L3	0.9825	0.0107	5.3994	1.8128	L3	0.8619	0.0814	5.5554	1.6108
L4	0.9808	0.0149	4.6953	0.9893	L4	0.8448	0.1787	4.3482	2.3379
L5	0.9769	0.0128	5.0742	1.6981	L5	0.8549	0.1334	3.1846	1.2564
S1	0.9571	0.0737	6.1414	3.1866	S1	0.7244	0.1770	4.9273	1.5180
Pelvis	0.9828	0.0120	3.9020	1.2659	Pelvis	0.9107	0.0850	2.3601	0.8334
Right bending					*Left binding*				
T11	0.9764	0.0107	3.2343	1.3176	T11	0.9791	0.0162	3.0115	0.9214
T12	0.9749	0.0114	3.2165	0.8332	T12	0.9756	0.0189	3.2180	0.9983
L1	0.9732	0.0169	3.0311	0.8925	L1	0.9727	0.0161	2.8361	0.5129
L2	0.9712	0.0171	2.5514	0.6455	L2	0.9724	0.0144	2.8897	0.9306
L3	0.9642	0.0202	3.3927	1.0717	L3	0.9713	0.0120	2.6166	0.7090
L4	0.9516	0.0304	3.1891	1.4171	L4	0.9563	0.0244	2.5242	0.6444
L5	0.8196	0.2048	2.8115	0.8692	L5	0.9197	0.0534	2.5772	1.2202
S1	0.7851	0.1949	2.4240	1.6776	S1	0.8252	0.0905	2.2406	0.8210
Pelvis	0.9754	0.0170	1.5463	0.6201	Pelvis	0.9837	0.0108	1.6080	0.6943
Right rotation					*Left rotation*				
T11	0.9799	0.0161	4.4377	1.5609	T11	0.9746	0.0348	5.1357	2.0063
T12	0.9867	0.0084	4.5688	1.2829	T12	0.9814	0.0174	4.8007	0.9545
L1	0.9864	0.0114	3.8967	0.7904	L1	0.9831	0.0134	4.2076	1.4473
L2	0.9869	0.0057	5.1414	2.2327	L2	0.9837	0.0208	3.9390	1.4184
L3	0.9885	0.0086	3.8651	0.9837	L3	0.9877	0.0115	4.1140	1.2261
L4	0.9877	0.0090	4.3158	1.3225	L4	0.9890	0.0103	3.9917	1.1793
L5	0.9872	0.0086	4.1603	0.9679	L5	0.9885	0.0100	3.8845	1.1514
S1	0.9856	0.0088	4.5970	1.0699	S1	0.9882	0.0103	3.9680	1.2404
Pelvis	0.9874	0.0100	3.8947	0.9113	Pelvis	0.9895	0.0091	3.7941	1.2113

Repeatability analysis for interoperator remarking

Table III shows the interoperator repeatability of MA of the lumbar spine performed through ZooMS.

Data are very similar to those obtained in the analysis of the intraoperator repeatability: r^2 is generally always next to 1, with an optimum correspondence in flexion and axial rotation movements, with a good values in lateral bending (the worst values are at L5 and S1 levels) whilst the extension shows a higher variability for all the levels. Again also e_{rms} is always limited to very few degrees.

Repeatability analysis for circadian remarking

Table IV shows the results of the circadian repeatability. Also in this case the repeatability results are satisfying: r^2 is close to 1 in most cases (lower values are shown only for the sacrum bone during lateral bending and extension); the root mean square error is comparable to that observed in the previous analysis and always limited to less than 5° at every level.

In Figure 3 an example of the repeatability analysis for patient 2 is shown.

Discussion

The method here presented, ZooMS, represents the first non-invasive structured systematic approach to evaluate the vertebral mobility of the single FU and considers the free natural strategy of the execution of the movements. Its application requires a system for human MA, but its relative

TABLE IV.—*Circadian repeatability of motion analysis of the lumbar spine performed through ZooMS.*

	r_2		e_{rms}			r_2		e_{rms}	
	Mean	SD	Mean	SD		Mean	SD	Mean	SD
Flexion					*Extension*				
T11	0.9889	0.0050	5.4698	1.1603	T11	0.9144	0.0452	4.5442	1.4834
T12	0.9896	0.0061	5.3882	1.4263	T12	0.9124	0.0454	4.5171	1.4610
L1	0.9880	0.0064	6.0487	1.8772	L1	0.8613	0.0260	5.6666	0.9866
L2	0.9857	0.0074	6.0215	1.5820	L2	0.8711	0.0735	4.9233	0.9056
L3	0.9855	0.0091	5.3571	1.0686	L3	0.8835	0.0539	4.7615	1.3172
L4	0.9811	0.0141	4.7634	1.7242	L4	0.8705	0.0533	4.1189	0.9837
L5	0.9781	0.0204	4.5806	1.2350	L5	0.8373	0.1045	3.5584	0.9109
S1	0.9690	0.0244	5.0440	1.8122	S1	0.6548	0.2048	4.5782	1.3646
Pelvis	0.9837	0.0083	3.6551	1.5325	Pelvis	0.9023	0.0784	2.5539	0.8325
Right bending					*Left binding*				
T11	0.9731	0.0154	3.0933	0.9141	T11	0.9793	0.0123	3.4803	0.9872
T12	0.9702	0.0128	3.4951	1.0009	T12	0.9787	0.0137	2.9230	0.9011
L1	0.9717	0.0162	2.8314	0.6197	L1	0.9734	0.0162	5.5871	1.2076
L2	0.9666	0.0121	2.6919	0.5212	L2	0.9678	0.0167	3.2689	1.1664
L3	0.9573	0.0236	3.3181	1.4401	L3	0.9615	0.0184	3.4937	1.5570
L4	0.9367	0.0436	3.4623	1.7826	L4	0.9376	0.0462	3.3749	1.3554
L5	0.8170	0.1521	2.9056	1.1066	L5	0.8963	0.0527	3.0440	1.6269
S1	0.7726	0.1165	2.0029	0.9623	S1	0.7865	0.0981	2.5338	0.8984
Pelvis	0.9774	0.0136	2.1308	1.0745	Pelvis	0.9732	0.0120	2.0166	1.1752
Right rotation					*Left rotation*				
T11	0.9766	0.0254	4.5060	1.5709	T11	0.9764	0.0129	4.6539	1.2654
T12	0.9722	0.0230	5.7095	1.6934	T12	0.9728	0.0207	4.8151	1.1342
L1	0.9772	0.0160	5.2784	2.0914	L1	0.9785	0.0167	4.3438	0.9981
L2	0.9828	0.0109	4.9269	2.1622	L2	0.9796	0.0189	4.4164	0.9480
L3	0.9784	0.0143	4.7392	1.4154	L3	0.9853	0.0112	4.3141	1.0805
L4	0.9825	0.0153	4.8869	1.8938	L4	0.9806	0.0117	4.4852	0.9522
L5	0.9812	0.0166	4.8241	2.4785	L5	0.9809	0.0136	4.5751	1.6391
S1	0.9788	0.0167	5.7811	2.2675	S1	0.9798	0.0134	4.0615	1.2054
Pelvis	0.9812	0.0168	4.8739	2.6512	Pelvis	0.9805	0.0150	4.2340	1.3392

simplicity (studied in close connection with the clinicians) makes it suitable for a daily use in clinical practice. The time needed for the examination is 30 min for subject preparation, data recording and subject dis-markering and 1 h for data processing and reporting. This time was carefully verified during the tests.

The validation of the protocol is satisfactory both concerning the comparison with literature data and repeatability tests.

In fact the RoM computed through ZooMS and literature findings (Table I) show a good correspondence, even if obtained with methodologies that are significantly different. Actually the RoMs of ZooMS and White *et al.*[20] are quite similar above all in flexion/extension and one side lateral bending, which are the most involved in the mobility of the lumbar spine. RA of movement shows good correspondence in lateral bending (above all in L1-L2, L2-L3, L3-L4 FUs) and quite good in flexion/extension movements, even if ZooMS seems to overestimate White *et al.* data. A similar situation could be observed in the axial rotation. However, it should be remembered that ZooMS and Withe *et al.* data refer to very different methodologies: first of all, the former gets information directly on subjects, while the latter uses cadaveric specimens. Secondly, ZooMS measures the motor functionally, both quantitatively (RoM) and qualitatively (MA), *i.e.* motor strategy of the subject.

On the other hand, few differences are introduced by the analysis of the 3 main variability factors. The more critical vertebral level is the sacrum

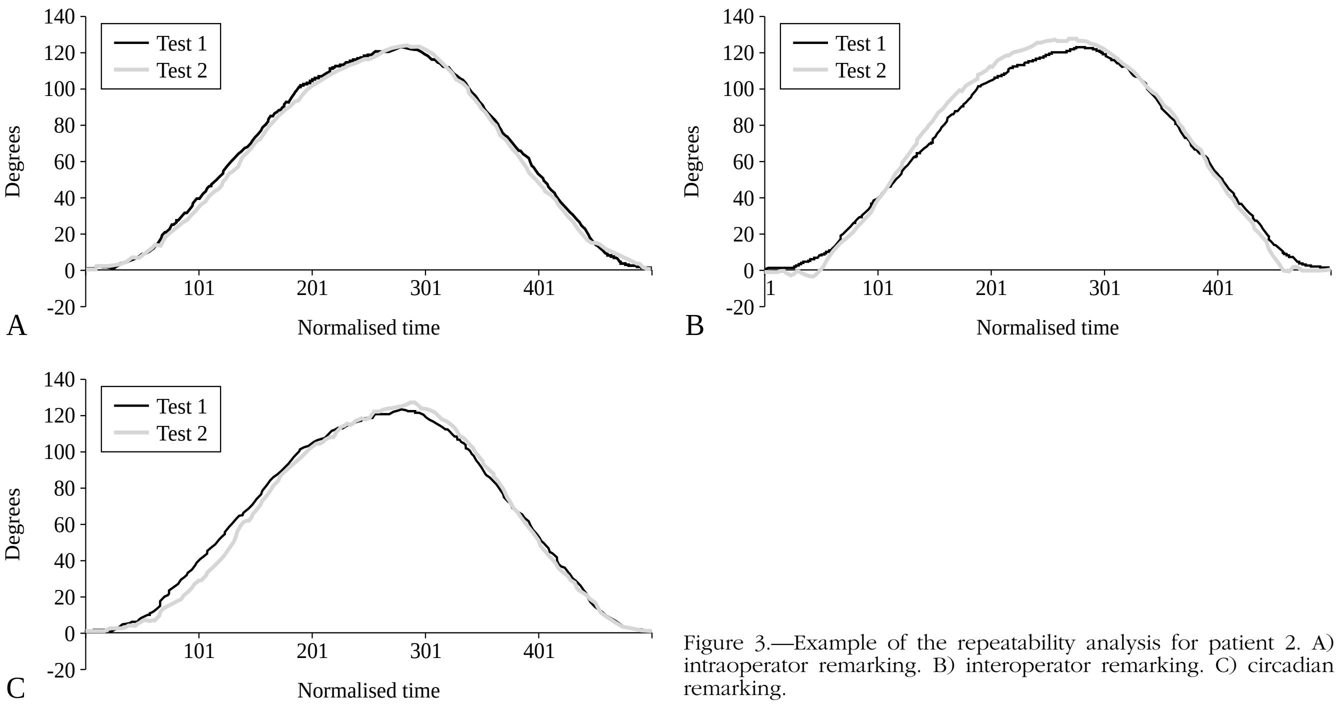

Figure 3.—Example of the repeatability analysis for patient 2. A) intraoperator remarking. B) interoperator remarking. C) circadian remarking.

bone, where the artefacts produced by the muscular contraction and by the sliding of the skin are more relevant: the mean values of r^2 are the lowest recorded and the % e_{rms} the greatest ones.

The most critical movement in terms of repeatability is the extension, probably due to skin movement artefacts.

The best repeatability is shown when the subjects perform rotations and flexions (always r^2 >0.95 at every FU level). The lateral bending shows a slightly inferior performance (r^2 between 0.7 and 0.82 for the sacrum but generally greater than 0.95 in the other levels).

To sum up these results allow to draw the conclusion that the proposed protocol is reliable and repeatable. Of course a conclusive validation should be obtained through a simultaneous radiographic investigation, but it is actually not feasible because of the limitation to the TV-cameras field of view by the X-ray devices. The unavoidable errors are the slide of the skin over the bony masses and the muscular contractions that slightly modify the morphology of the back during the movement.

Nowadays, the radiographic method still remains the principal tool of analysis of the vertebral column: its results are precise and reliable, but inadequate for functional and dynamic studies. For the subjects affected from serious pathologies, dynamic radiographies are commonly used, but these are limited to analyze the positions assumed by the subject at the beginning and at the end of the movement, so as to lose the whole information on the pattern of the movement. This limit can be overcome using cine-radiographic methods that, however, are highly invasive for the massive usage of X-rays.

But with respect to the radiographic methods, ZooMS combines and balances the absolute non invasive approach with a not absolute but high precision (this last characteristic is due to the indirect measure of the movement through superficial anatomical points) and allows for a frequent exam repetition during the treatment and the follow-up; with respect to the other non invasive methods it also offers the possibility to assess the single FU contribution as well as the complete spine mobility.

Another positive characteristic is the 3D assessment of the free natural movements of the spine and considering all the contributions to the movement by each rotation axis (principal and secondaries). This is surely an innovation with respect to any other previous methods in literature.

Also the information related to the patterns of movement is a fundamental and innovative outcome of the ZooMS methodology; it could be very useful for the clinical diagnosis and in fact it can evidence the limitations and the strategies adopted to compensate for the functional limitations in the execution of the movements.

The encouraging results of ZooMS make it a very promising protocol for clinicians; an application to the follow-up of a rehabilitative treatment of back pain is in progress. In this case the continuous screening of the patients during the treatment to evaluate its effectiveness and eventually its customization are the main purposes of ZooMS.

Conclusions

To support diagnosis and rehabilitation decisions radiology is the most common method in evaluating back pain, but it is an invasive and static technique. The clinical demand of a non invasive and accurate protocol was faced in the development of the presented methodology to provide for a FU analysis, together with the evaluation of the global movement of the spine (*i.e.* L1-L5 tract). ZooMS is based on optoelectronic technique and on a simple and repeatability protocol of analysis. The most important advantages of ZooMS are to be a non invasive and dynamic technique, to be used how many times is required, *i.e.* in clinical applications this protocol could be useful to evaluate the follow-up of a rehabilitation treatment. Moreover RoM gives quantitative and qualitative results which reflect the subjectivity of people in executing the movement: in fact the analysis consists on the evaluation of simple, free and usual movements of subjects without any constrains so to better analyze the common movements daily performed by people. This protocol was validated on a sample of 10 healthy males; results seems good both if compared with literature findings and concerning the repeatability analysis. Furthermore these data allowed for creating a data collection for next clinical applications to evaluate and compare the mobility of pathological subjects with normalcy.

Finally, ZooMS is going to be applied to other tracts of the vertebral column, in particular to the cervical one, above all to study whiplash injuries.

Acknowledgements.—The authors thank Dr. Eng. M. Marocco and Dr Eng. M. C. Molinaro for their helpful support in this research.

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