ULTRASONOGRAPHIC CRITERIA FOR THE DIAGNOSIS OF INCOMPETENCE OF THE CERVIX UTERI

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ABSTRACT

It is evident that the uterine cervix structure determines its nature, and hence its degree of incompetence. An increased water content changes the tissue density, and hence changes the sound velocity in the cervix.

The distance between the gestational sac and the internal os is measured at different weeks of pregnancy for the competent and incompetent cases. The sac reaches the cervical border earlier in the incompetent case. The length of the cervix is also measured for both cases at different urinary bladder capacity.

A hydraulic model is also developed to predict the elasticity of the cervix in both cases. The use of a tissue signature parameter, viz the backscattering coefficient might be helpful to assess the degree of competence.

INTRODUCTION

The diagnosis of cervical incompetence can be achieved by evaluating the clinical history of multigravid patients. If the typical history of incompetence is not noted, the clinician may rely on observing the appearance of symptoms which are usually observed late in the course of this condition. The condition is more complex for primigravid patients with congenital incompetence, the diagnosis is almost always missed entirely [1].

Until the eighth week of pregnancy the structural configuration of the body, isthmus and cervix is the same as in the non-pregnant uterus. Until the twelfth week there is hypertrophy with consequent lengthening and thickening of the isthmus, as takes place in the rest of the uterine body.

The cervix consists mainly of fibrous tissue with varying quantities of smooth muscle; the inner part of the cervix is mainly collagenous, with some scattered nonfunctional muscle fibers.

During labor, elevation of the proportion of mucopolysaccharide to collagen above a critical level is associated with an influx of water into the tissues. This produces an imbalance between the cohesive and dispersive forces interacting between collagen structural units. Immediately postpartum the excess water is absorbed and the cervical collagen structure returns to its prepartum level of compliance [1]. It is thus clear that the uterine cervix structure determines its elastic nature, and hence its degree of competence.

METHODOLOGY AND RESULTS

Measurement of the sound velocity in an elastic tissue will give information about its density and elasticity. The speed of propagation in tissue is given by:

$$c = \left[\frac{E}{\rho} \frac{(1 - \delta)}{(1 + \delta)(1 - 2\delta)} \right]^{0.5} \qquad (1)$$

wher E is Young's modulus of elasticity, ρ the density, and δ Poisson's ratio.

Each kind of tissue has its characteristic density and elasticity, hence a characteristic speed "c" of propagation for longitudinal oscillations. Changes in elasticity and/or density of the tissue will accordingly appear as a change in the sound velocity, provided there is no change by a costant ratio [2].

It is thus clear that the competent cervix uteri has a more elastic nature than the incompetent cervix [3]. Using conventional invasive, nonultrasonic techniques are neither specific nor sensitive for predicting the degree of incompetence. A noninvasive, ultrasonic technique using inner body forces may then be of value in this respect and is the subject of the present investigation.

The first step is to measure the cervical resting length, the resting diameter, and the angle between the longitudinal axis of the cervix and that of the bladder. This is all done with an absolutely empty urinary bladder. The cervical elongation, bladder volume and cervical diameter are all measured when the bladder is full. Figs. (1 and 2) depict the cervical elongation vs bladder volume for the competent and incompetent cases, whereas Figs. (3 and 4) depict the cervical strain vs the effective normal forces applied by the bladder against the uterine cervix.

Fig. (5) shows the distance between the gestational sac and the internal os vs different weeks of gestation for competent and incompetent cases. Figs. (6 and 7) show the cervical strain vs weeks of pregnancy for both cases. Figs. (8 and 9) show the cervical strain plotted vs the normal stress resulting from the bladder load on the cervical domain, from which an estimate of Young's modulus of elasticity and Poisson's ratio can be computed. Using Eq. (1), the sound velocity can then be estimated, and the results are shown in Table (1).

A tissue signature parameter, the backscattering coefficient is also computed. This coefficient is defined as the scattered power (owing to random reflections resulting at an interface between two media of mismatched impedances) per unit solid angle per unit incident intensity and unit scattering volume, when the incident and scattered beams are opposite to each other in direction (ie., when the same transducer is used as the transmitter and receiver). This coefficient is measured in $cm^{-1}Sr^{-1}$ [4]. Mathematically the backscattering coefficient μ_{bs} is expressed as

$$\mu_{bs} = \frac{P_m}{4\pi V}$$

$$\text{where } P_m = \text{scattered power} = \frac{\tau_k^2 \; k_o^4 \; a^2}{\pi \; R_D^2 \; (1 + 4 \; k_o^2 \; a^2)^2} \qquad (2)$$

τ_k = fractional compressibility variation
k_o = wave number = $2\pi f/c$
R_D = range of the transducer
a = average scatterer separation
V = scattering volume

Fig. (10) shows the backscattering coefficient vs different weeks of gestation for the competent and incompetent cases. Figs. (11 and 12) show the backscattering coefficient vs attenuation for all competent and incompetent cases, while the results are shown in Table (2).

A simple model for the human cervix uteri during the first trimester has been developed.

Fung, (1967), found that for soft biological tissue in a tension experiment the tension-length relationship is exponential. For moderate strains involved in cervical elongation, the linear stress-strain relation may be poor and an exponentially elastic property is considered [5].

The simplest exponential tension-length relation is

$$F = A \exp[B (L-L_o)] \quad (2)$$

$$\delta L = L-L_o = (1/B) \ln (F/A)$$

where δL is the longitudinal extension, A and B are tissue constants; A is proportional to the applied force while B is a function of elasticity. It is evident that Eq. (2) exhibits a non-zero stress at zero strain. There are three reasons supporting this statement:

1) Soft tissue is in a state of initial stress at its normal length.
2) Synder, (1972), found that adding a constant to make the stress equal to zero when the strain is zero creates computational difficulty.
3) For large strains the effect of initial stress is small.

By applying the previously described technique of using the bladder as the source of force causing cervical elongation with force analysis and Newton's law of forces, and since the resultant tensile force is exponential, it turns out that:

$$F = T + K + e$$

$$F = A \exp[B (L-L_o)]$$

T = normal force applied by the bladder on the cervical tissue
K = initial force at zero strain
e = error term
A and B are tissue constants.

The following are some assumptions that underlie this way of modeling:

1- The system consists of the uterus, cervix, and urinary bladder.
2- The force applied by the bladder is the driving force.
3- Frictional and inertial forces are negligible.

The model, which was merely developed for nonpregnant cases and first trimester pregnant cases only considers the effect of the bladder volume on cervical extension, while it neglects the effect of this volume on the uterus. This is because the force exerted by the bladder on the body of the uterus is small when compared to the very strong muscles in the uterine wall, in addition to the fact that the uterus moves transversely to be only in the antiflexed position, i.e. coaxial with the cervix. This transverse movement is also limited as a result of the attachment of the uterus to the posterior aspect of the pelvis by border and round ligaments.

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3] R.H. Phillpott, "Biodynamics of the Cervix", in the Cervix", Chap. 10, W.B. Saunders, 1976.

4] D. Nicholas, "Evaluation of Backscattering Coefficients for Excised Human Tissues: Results, Interpretation and Associated Mesurement", Ultrasound in Med. & Biol., Vol. 8, pp. 17-28, 1982.

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Table (1-a)

Competent

Case	ϵ	Ro	R1	ΔR	δ	F	γ	E	C
1	0.367	1.3	1.28	0.02	0.015	0.315	0.06	0.17	1520
2	0.129	1.36	1.33	0.03	0.02	1.02	0.18	1.36	1560
3	0.0714	1.4	1.4	0	0	1.5	0.2	3.3	1630
4	0.083	1.3	1.3	0	0	1.19	0.22	2.72	1645
5	0.273	1.28	1.25	0.03	0.109	1.56	0.30	1.10	1610
6	0.107	1.2	1.16	0.04	0.374	1.315	0.29	2.72	1635

Table (1-b)

Incompetent

Case	ϵ	Ro	R1	ΔR	δ	F	γ	E	C
1	0.367	1.3	1.28	0.02	0.015	0.315	0.06	0.17	1520
2	0.129	1.36	1.33	0.03	0.02	1.02	0.18	1.36	1560
3	0.0714	1.4	1.4	0	0	1.5	0.2	3.3	1630
4	0.25	1.32	1.29	0.03	0.023	1.44	0.27	0.69	1600
5	0.25	1.3	1.27	0.03	0.023	0.3	0.06	0.23	1520
6	0.24	1.34	1.32	0.02	0.015	0.53	0.09	0.39	1580

Table (1-c)

Competent Pregnant

Case	$\in$	Ro	RI	ΔR	δ	F	σ	E	C
1	0.704	1.2	1.0	0.015	0.167	0.113	0.025	0.035	1529
2	0.082	1.2	1.2	0	0	0.13	0.0287	0.35	1530
3	0.07	1.1	1.1	0	0	0.89	0.236	3.36	1670
4	0.622	1.19	1.0	0.19	0.173	1.64	0.37	0.95	1600
5	0.318	1.22	1.2	0.02	0.016	1.89	0.42	1.31	1625
6	0.65	1.2	1.06	0.14	0.083	2.16	0.48	0.74	1540
7	0.82	1.25	1.1	0.2	0.121	2.32	0.53	0.64	1580

Table (1-d)

Incompetent Pregnant

Case	$\in$	Ro	RI	ΔR	δ	F	σ	E	C
1	0.25	1.5	1.3	0.02	0.615	0.31	0.058	0.232	1520
2	0.24	1.65	1.35	0.3	0.925	0.528	0.09	0.414	1533
3	0.129	1.4	1.4	0	0	0.607	0.114	0.886	1560
4	0.36	1.4	1.3	0.1	0.002	0.653	0.123	0.341	1515
5	0.55	1.7	1.5	0.2	0.242	0.803	0..152	0.274	1545
6	0.409	1.6	1.4	0.3	0.436	1.514	0.285	0.697	1550
7	0.389	1.5	1.3	0.2	0.395	1.43	0.27	0.694	1560

Table (2-a)

COMPETENT

CASE	B.S.C	M.G.L	ATTENUATION	SOUND SPEED
1	0.034	30	0.00156	1690
2	0.015	25	0.0033	1650
3	0.0063	27	0.0132	1645
4	0.0002	20	0.343	1610
5	0.00014	19	0.414	1540
6	0.0036	18.03	0.0297	1530
7	0.00004	17.5	0.3987	1520

Table (2-b)

INCOMPETENT

CASE	B.S.C	M.G.L	ATTENUATION	SOUND SPEED
1	0.0036	29	0.0133	1620
2	0.0043	31	0.054	1630
3	0.0034	25	0.175	1540
4	0.0002	18.5	0.308	1525
5	0.0007	16	0.343	1560
6	0.0004	15.8	0.425	1520

Table (2-c)

COMPETENT\PERGNANT

CASE	B.S.C	M.G.L	ATTEN	WKS	S.SPEED
1	0.029	33	0.0017	5.5	1670
2	0.008	29	0.0418	10	1625
3	0.004	15	0.0543	16	1580
4	0.0013	25	0.071	20	1600
5	0.0004	23	0.269	22.5	1540
6	0.00034	19	0.434	27	1529
7	0.00032	18.03	0.535	29	1530

Table (2-d)

INCOMPETENT\PERGNANT

CASE	B.S.C	M.G.L	ATTEN	WKS	S.SPEED
1	0.021	30	0.0414	7	1560
2	0.059	29	0.0198	12	1520
3	0.0024	29	0.0388	16	1560
4	0.0036	25	0.1334	22	1545
5	0.0002	19.5	0.308	25	1529
6	0.00007	16	0.343	30	1533
7	0.00004	15.8	0.425	35	1515

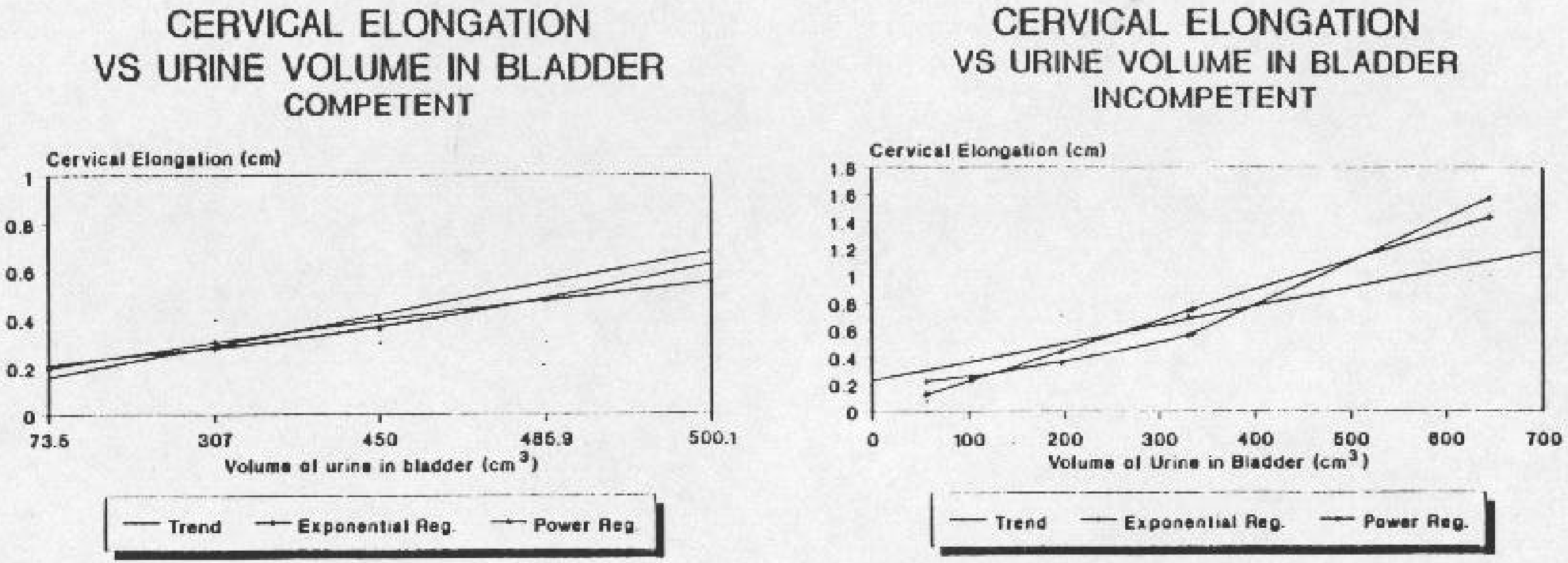

CERVICAL ELONGATION
VS URINE VOLUME IN BLADDER
COMPETENT
Cervical Elongation (cm)
1
0.8
0.6
0.4
0.2
0
73.5
307
450
485.9
500.1
Volume of urine in bladder (cm³)
Trend
Exponential Reg.
Power Reg.
CERVICAL ELONGATION
VS URINE VOLUME IN BLADDER
INCOMPETENT
Cervical Elongation (cm)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
Volume of Urine in Bladder (cm³)
Trend
Exponential Reg.
Power Reg.

Fig. 1

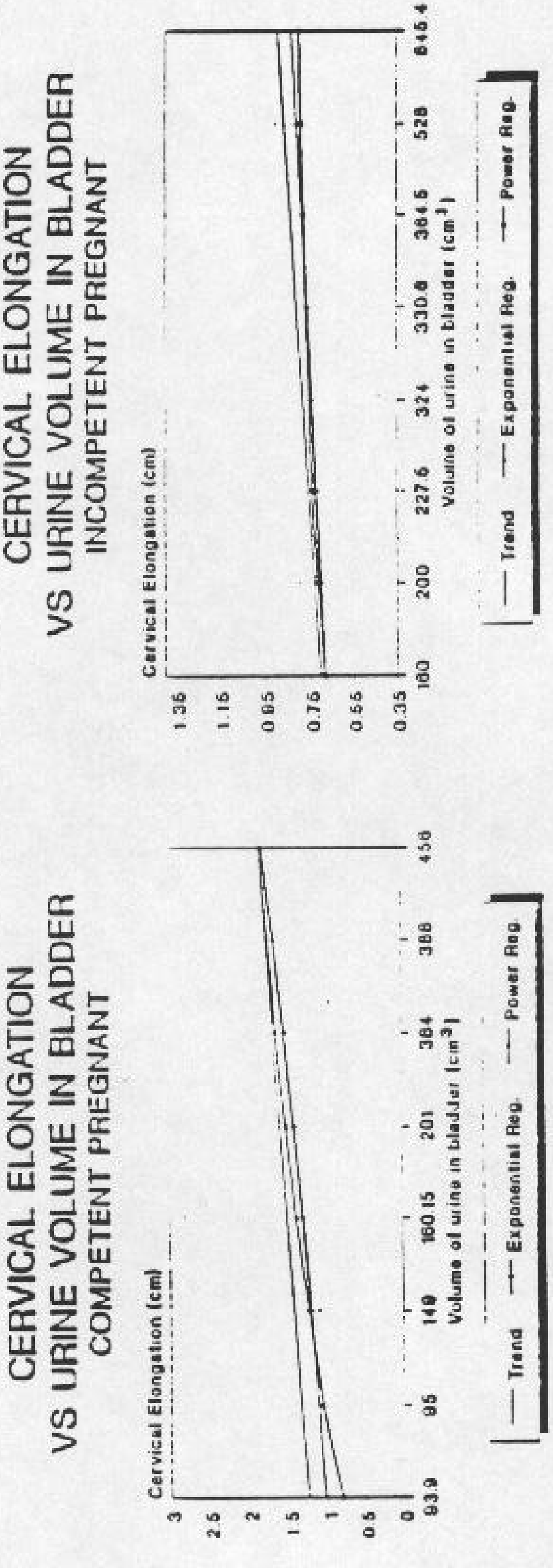

CERVICAL ELONGATION
VS URINE VOLUME IN BLADDER
COMPETENT PREGNANT
Cervical Elongation (cm)
3
2.5
2
1.5
1
0.5
0
93.9
95
149
160.15
201
384
388
456
Volume of urine in bladder (cm³)
Trend
Exponential Reg.
Power Reg.
CERVICAL ELONGATION
VS URINE VOLUME IN BLADDER
INCOMPETENT PREGNANT
Cervical Elongation (cm)
1.36
1.16
0.95
0.76
0.55
0.35
180
200
227.6
324
330.8
364.5
528
645.4
Volume of urine in bladder (cm³)
Trend
Exponential Reg.
Power Reg.

Fig. 2

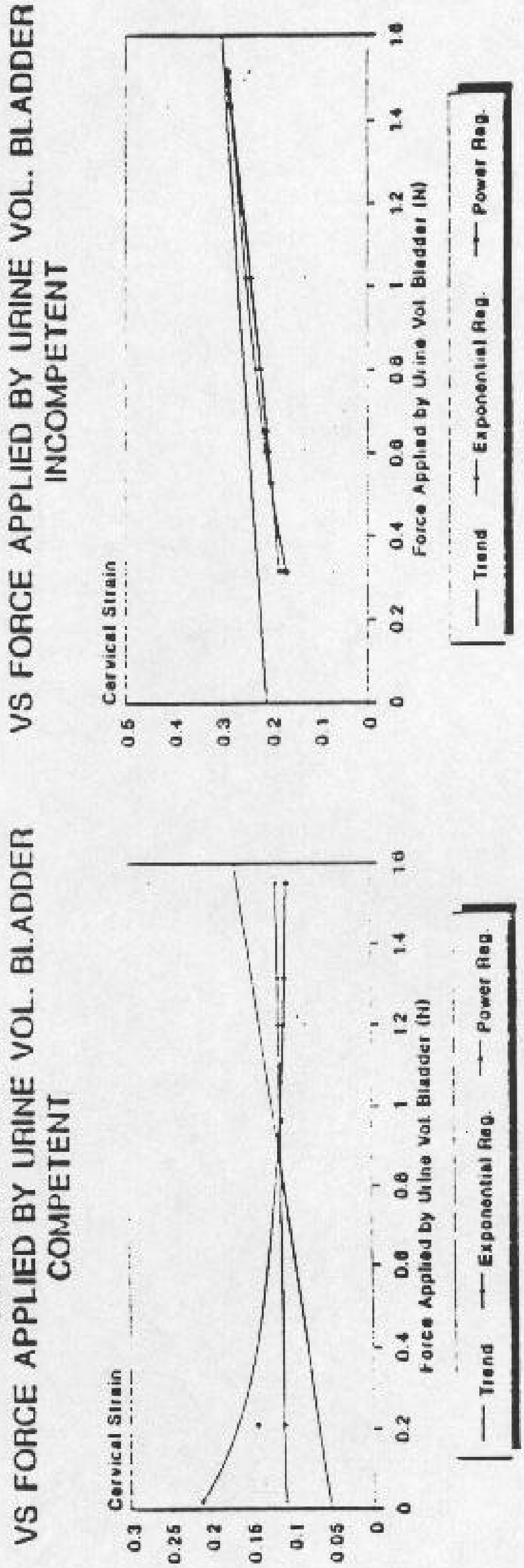

CERVICAL STRAIN
VS FORCE APPLIED BY URINE VOL. BLADDER
COMPETENT
Cervical Strain
Force Applied by Urine Vol. Bladder (N)
Trend
Exponential Reg.
Power Reg.
CERVICAL STRAIN
VS FORCE APPLIED BY URINE VOL. BLADDER
INCOMPETENT
Cervical Strain
Force Applied by Urine Vol. Bladder (N)
Trend
Exponential Reg.
Power Reg.

Fig. 3

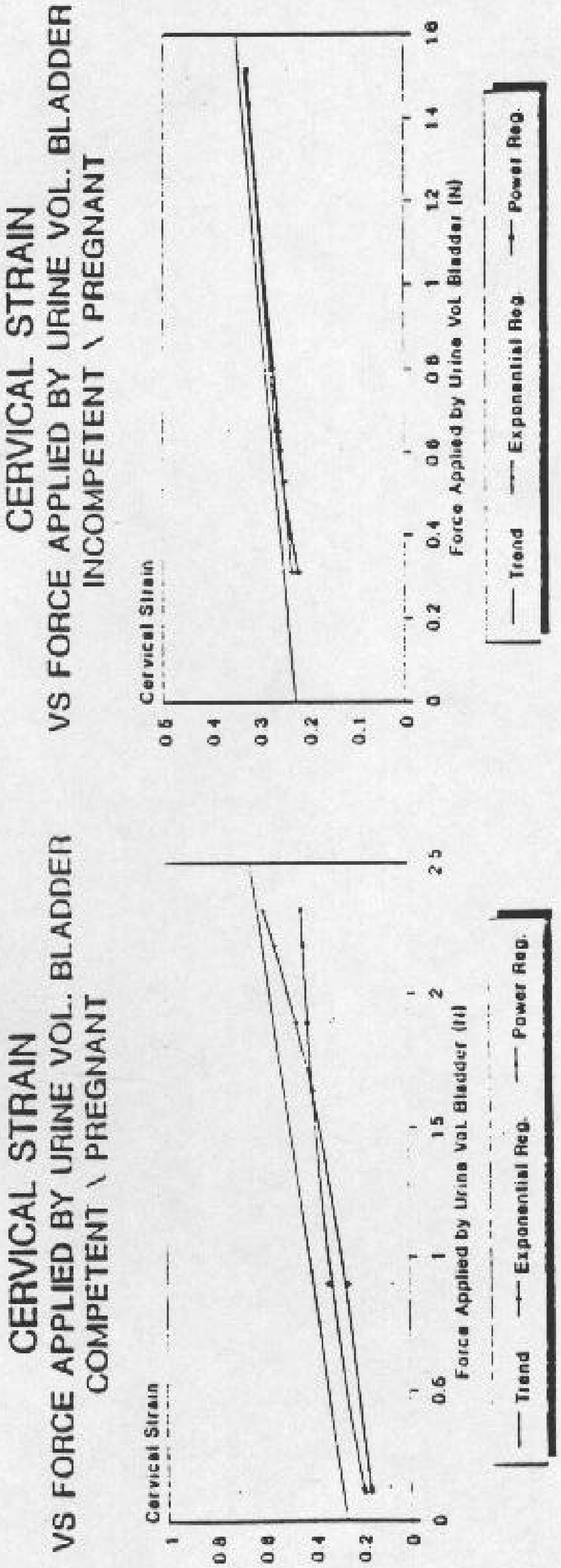
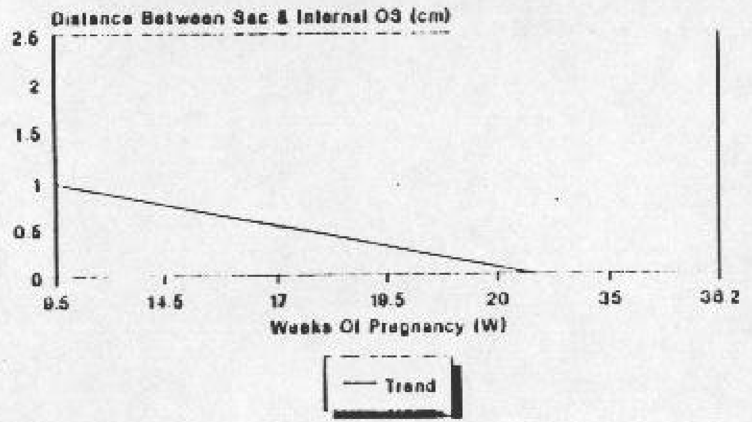

CERVICAL STRAIN
VS FORCE APPLIED BY URINE VOL. BLADDER
COMPETENT \ PREGNANT
Cervical Strain
Force Applied by Urine Vol. Bladder (N)
Trend
Exponential Reg.
Power Reg.
CERVICAL STRAIN
VS FORCE APPLIED BY URINE VOL. BLADDER
INCOMPETENT \ PREGNANT
Cervical Strain
Force Applied by Urine Vol. Bladder (N)
Trend
Exponential Reg.
Power Reg.

Fig. 4

DISTANCE BETWEEN SAC & INTERNAL OS VS WEEKS OF PREGNANCY
COMPETENT PREGNANT



DISTANCE BETWEEN SAC&INTERNAL OS VS WEEKS OF PREGNANCY
INCOMPETENT PREGNANT

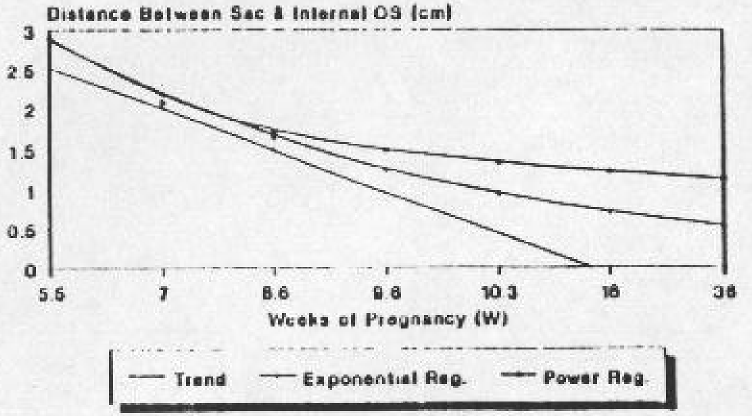
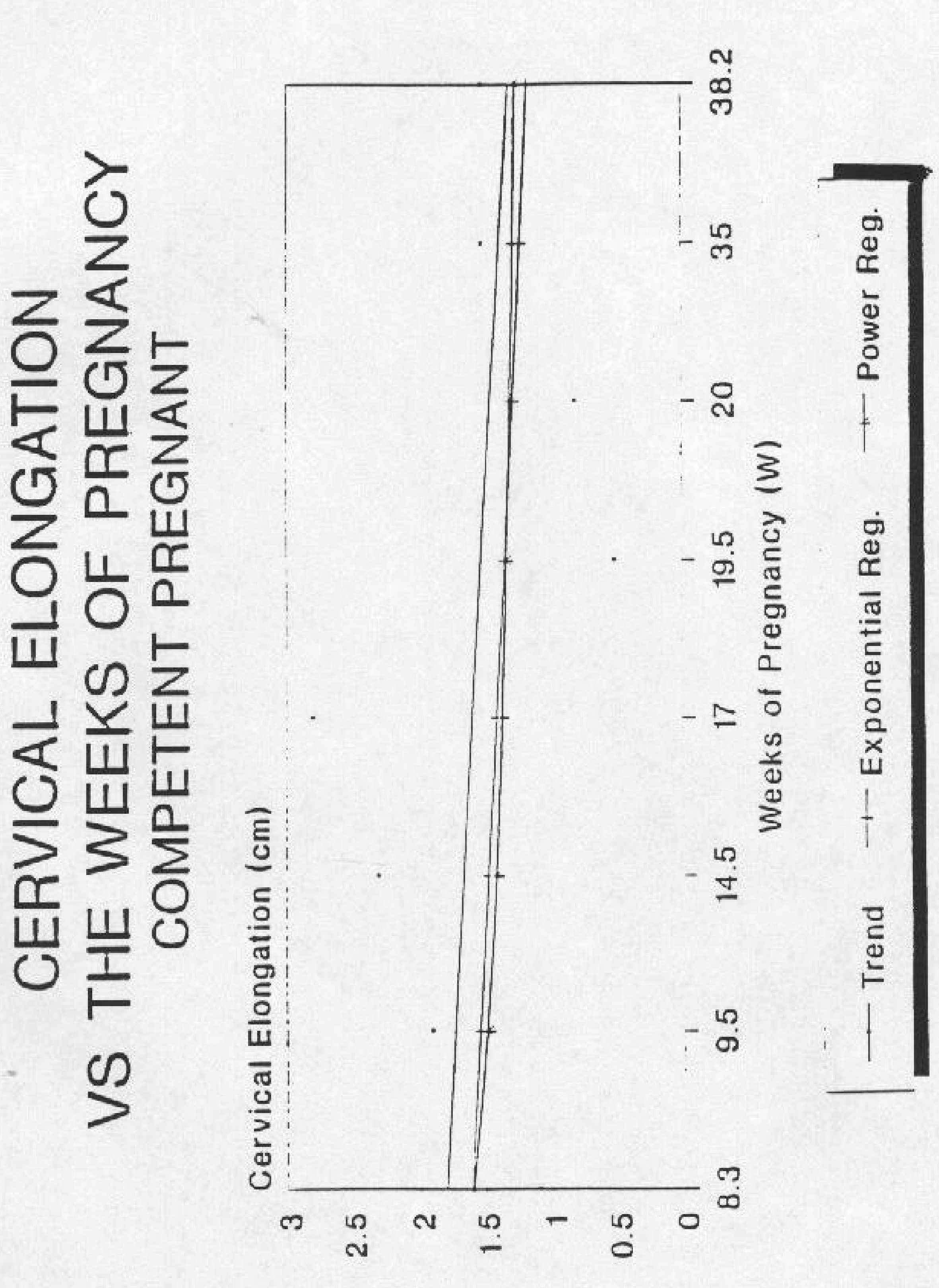


Fig. 5



CERVICAL ELONGATION
VS THE WEEKS OF PREGNANCY
COMPETENT PREGNANT
Cervical Elongation (cm)
3
2.5
2
1.5
1
0.5
0
8.3
9.5
14.5
17
19.5
20
35
38.2
Weeks of Pregnancy (W)
Trend
Exponential Reg.
Power Reg.

Fig. 6

CERVICAL ELONGATION VS THE WEEKS OF PREGNANCY
INCOMPETENT PREGNANT

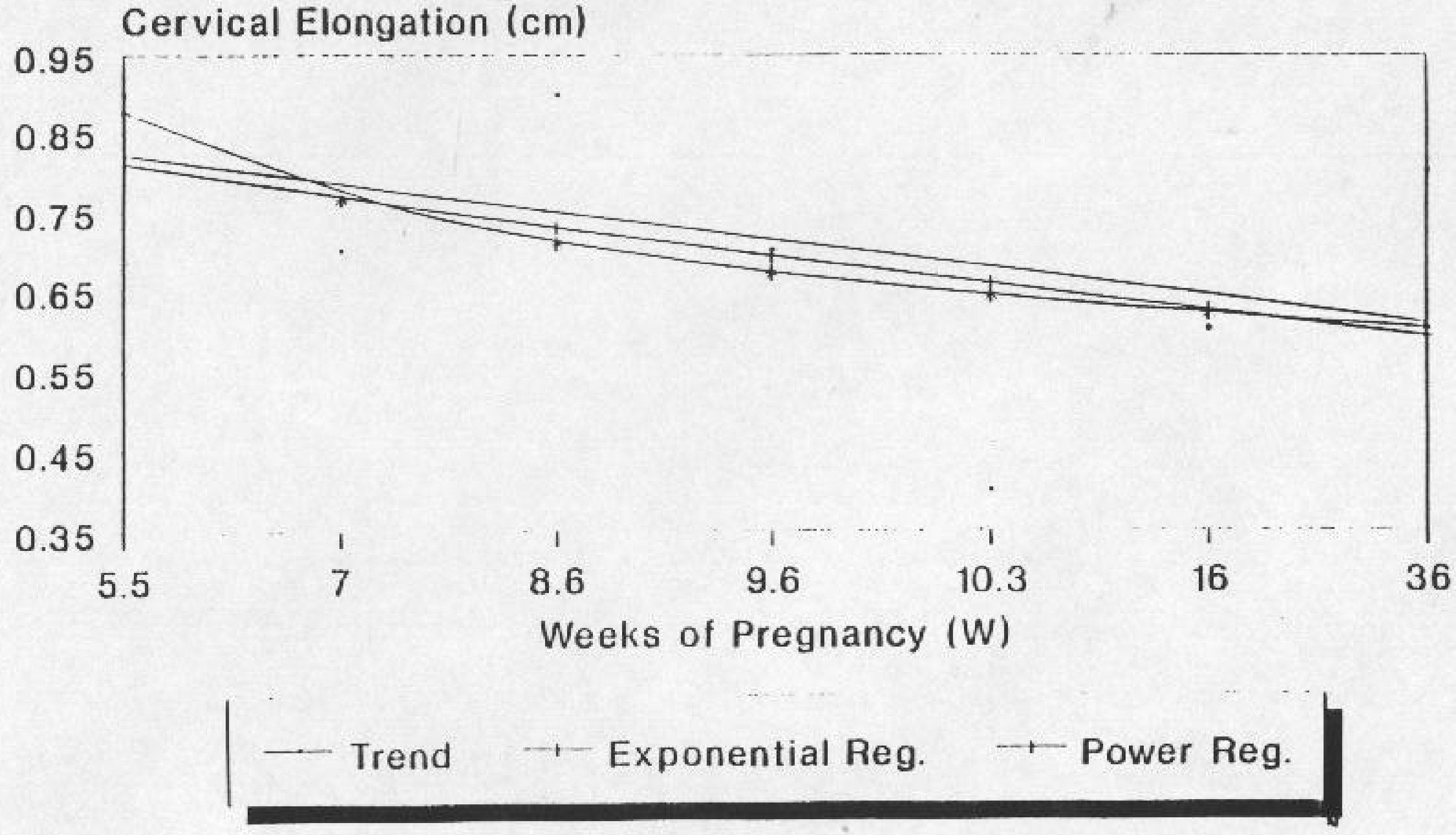
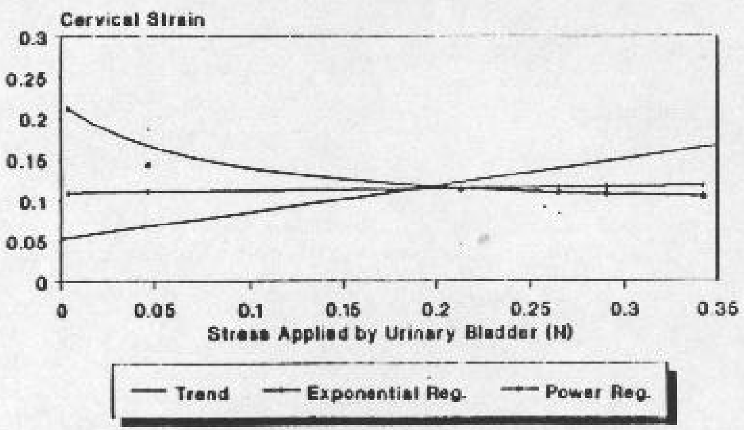


Fig. 7

CERVICAL STRAIN
VS STRESS APPLIED BY URINARY BLADDER
COMPETENT



CERVICAL STRAIN
VS STRESS APPLIED BY URINARY BLADDER
INCOMPETENT

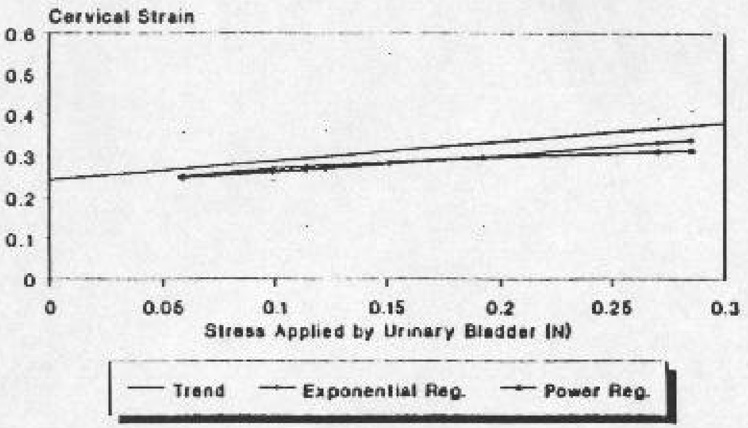


Fig. 8

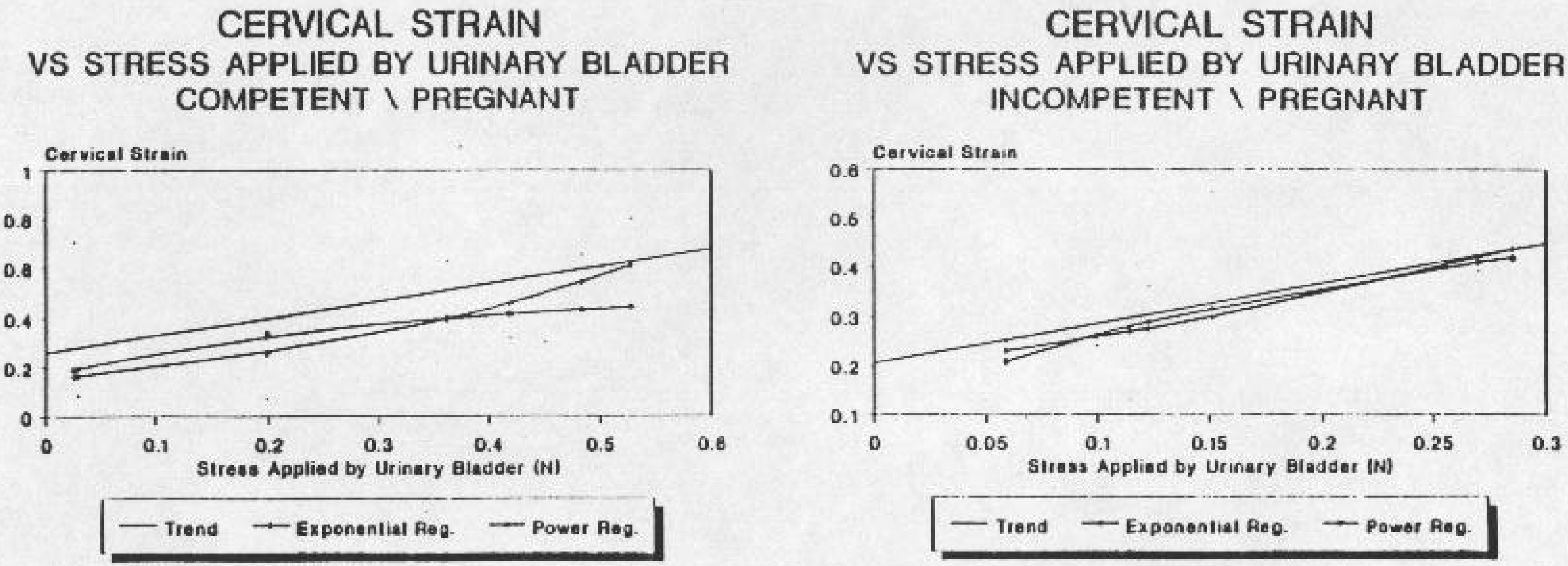

CERVICAL STRAIN
VS STRESS APPLIED BY URINARY BLADDER
COMPETENT \ PREGNANT
Cervical Strain
1
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Stress Applied by Urinary Bladder (N)
Trend
Exponential Reg.
Power Reg.
CERVICAL STRAIN
VS STRESS APPLIED BY URINARY BLADDER
INCOMPETENT \ PREGNANT
Cervical Strain
0.6
0.5
0.4
0.3
0.2
0.1
0
0.05
0.1
0.15
0.2
0.25
0.3
Stress Applied by Urinary Bladder (N)
Trend
Exponential Reg.
Power Reg.

Fig. 9

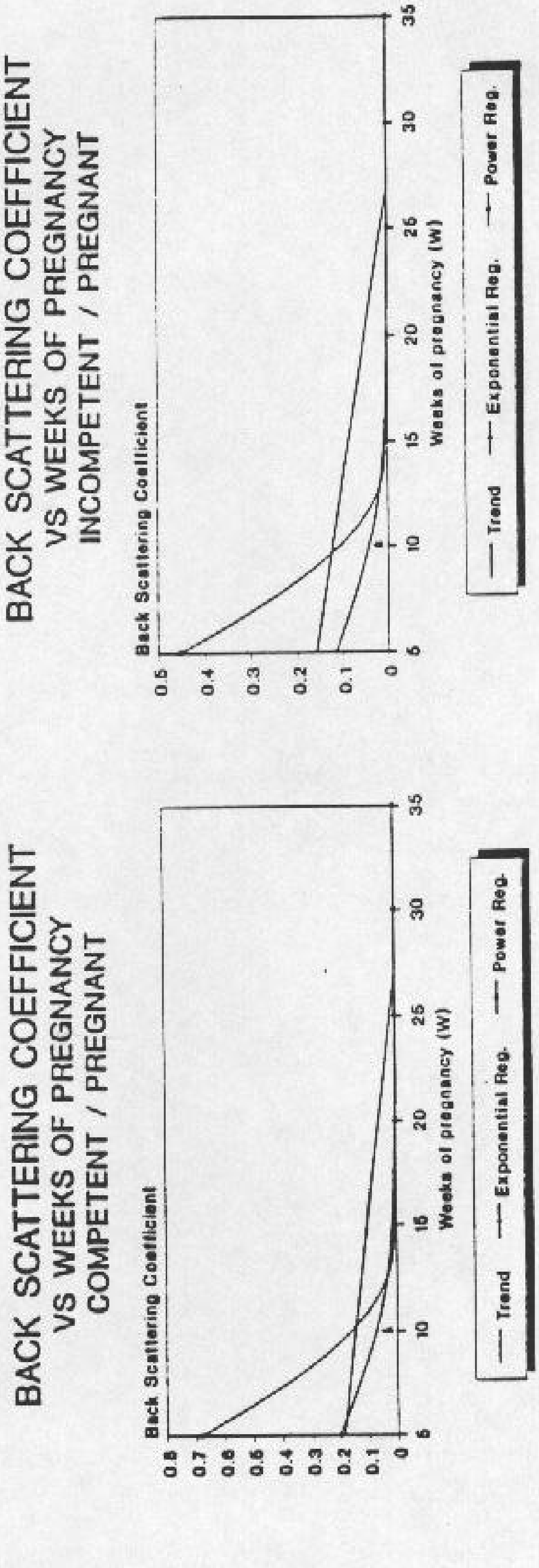

BACK SCATTERING COEFFICIENT
VS WEEKS OF PREGNANCY
COMPETENT / PREGNANT
Back Scattering Coefficient
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
25
30
35
Weeks of pregnancy (W)
Trend
Exponential Reg.
Power Reg.
BACK SCATTERING COEFFICIENT
VS WEEKS OF PREGNANCY
INCOMPETENT / PREGNANT
Back Scattering Coefficient
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
25
30
35
Weeks of pregnancy (W)
Trend
Exponential Reg.
Power Reg.

Fig. 10

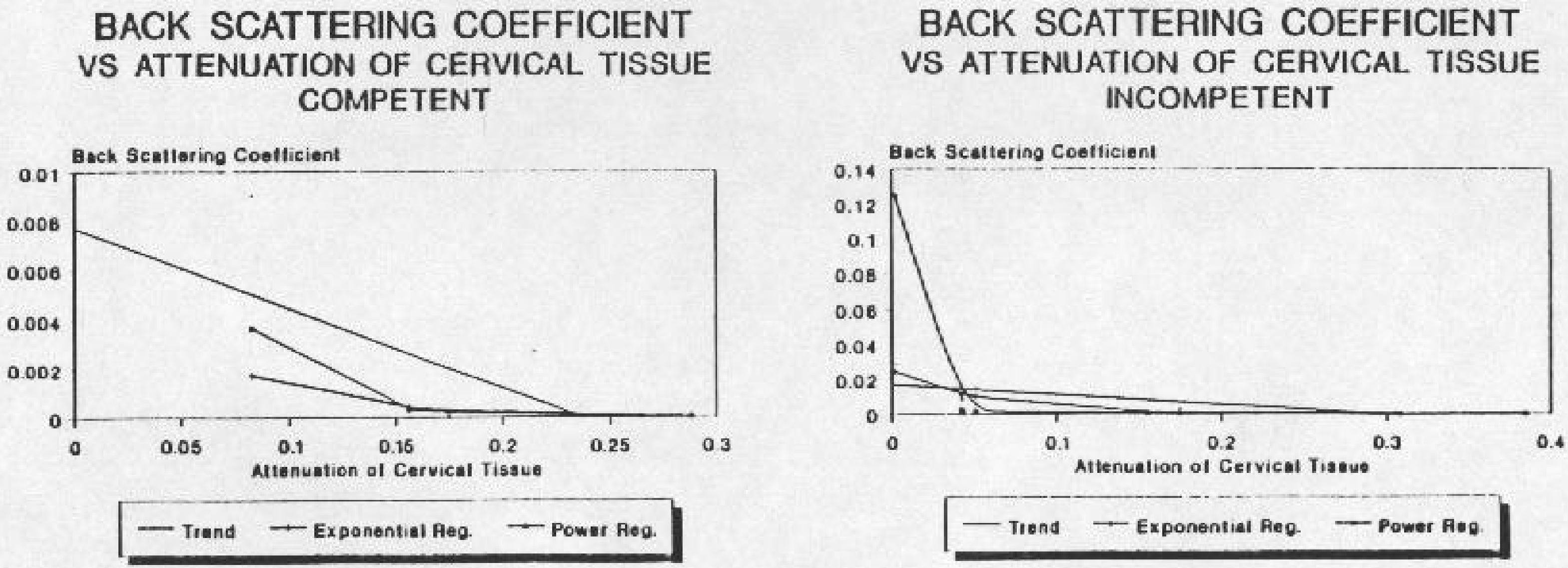

BACK SCATTERING COEFFICIENT
VS ATTENUATION OF CERVICAL TISSUE
COMPETENT
Back Scattering Coefficient
0.01
0.008
0.006
0.004
0.002
0
0
0.05
0.1
0.15
0.2
0.25
0.3
Attenuation of Cervical Tissue
Trend
Exponential Reg.
Power Reg.
BACK SCATTERING COEFFICIENT
VS ATTENUATION OF CERVICAL TISSUE
INCOMPETENT
Back Scattering Coefficient
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.1
0.2
0.3
0.4
Attenuation of Cervical Tissue
Trend
Exponential Reg.
Power Reg.

Fig. 11

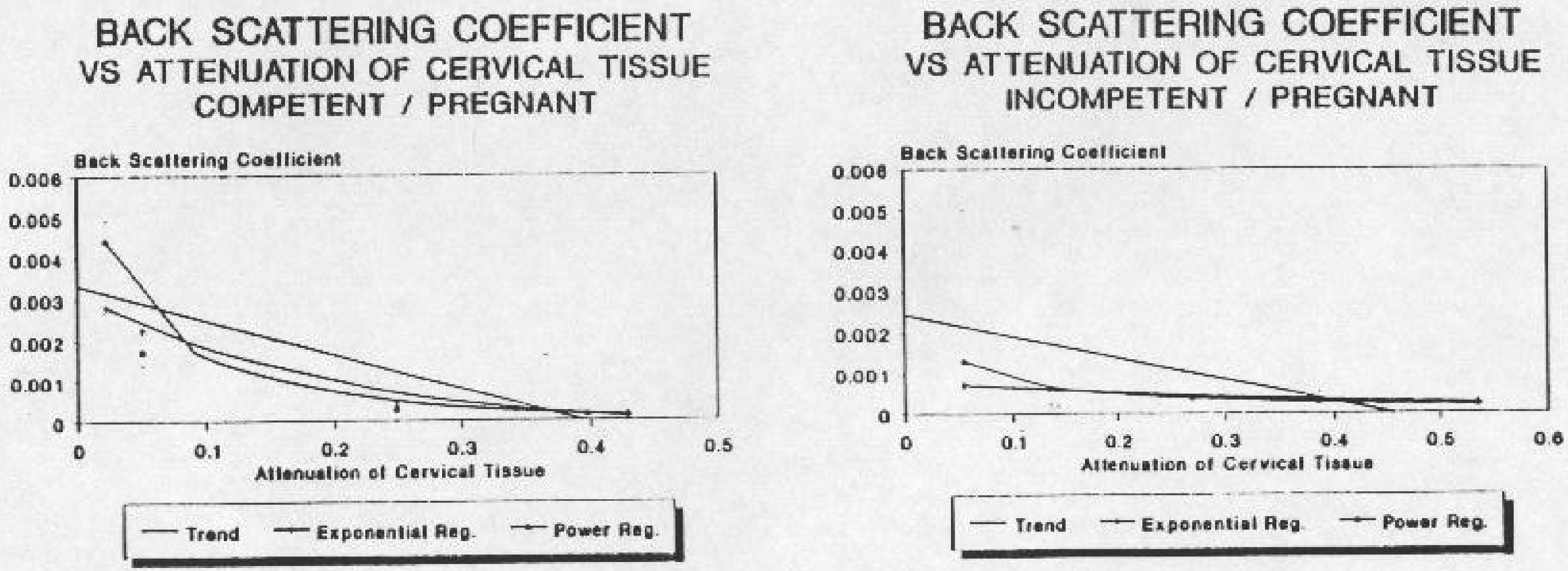

BACK SCATTERING COEFFICIENT
VS ATTENUATION OF CERVICAL TISSUE
COMPETENT / PREGNANT
Back Scattering Coefficient
0.006
0.005
0.004
0.003
0.002
0.001
0
0
0.1
0.2
0.3
0.4
0.5
Attenuation of Cervical Tissue
Trend
Exponential Reg.
Power Reg.
BACK SCATTERING COEFFICIENT
VS ATTENUATION OF CERVICAL TISSUE
INCOMPETENT / PREGNANT
Back Scattering Coefficient
0.006
0.005
0.004
0.003
0.002
0.001
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Attenuation of Cervical Tissue
Trend
Exponential Reg.
Power Reg.

Fig. 12